ASSESSMENT OF PHYSICOCHEMICAL AND BILOGICAL PROPERTIES OF HARVESTED RAINWATER IN GAMBANG AREA AND REMOVAL OF CONTAMINANTS USING SODIUM HYPOCHLORITE

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Civil Engineering & Earth Resources

UNIVERSITI MALAYSIA PAHANG

OCTOBER 2018

A special thanks and dedications to my beloved
Father in heaven, My beloved Mother
My two wonderful brothers for all the
Love and support and for being patient during my study

ACKNOWLEDGEMENTS

I would like to express my deep and sincere appreciation to my supervisor Mr. Abdul Syukor bin abd. Razak for his support and professional guidance and for giving me an opportunity to learn what research is all about. Special gratitude to my Co. Supervisor Dr. MD. Nurul Islam Siddique for his help, contributions, guidance and time for this research work.

Sincerely gratitude and thanks should be forwarded to Dr. Doh and Madam Azima for their continue help and support through my research study.

I would like also to express my deepest gratitude to my family especially my mother and my two brothers for their unconditional love, help, support, gaudiness and for their patience with me through my research study.

Finally, I would like to thank all my friends who helped and supported me through my study.

ABSTRAK

Sistem penuaian air hujan (RWH) merujuk kepada pengumpulan dan penyimpanan air hujan untuk kegunaan yang boleh diminum dan tidak boleh diminum. Kajian ini menjalankan penilaian kualiti sistem penuaian air hujan di Universiti Malaysia Pahang, Gambang, daerah kecil Pahang bagi kedua-dua ciri fizikokimia dan mikrobiologi untuk memperlihatkan potensi penuaian air hujan domestik untuk digunakan sebagai sumber air minum alternatif di kawasan luar bandar. Sampel air hujan dikumpulkan dari sistem penuaian air hujan (WASRA), Sistem Air untuk Kawasan Pedalaman secara mingguan selama tiga selang waktu atau yang dikenali sebagai musim monsun tenggara (pra monsun, monsun dan pasca monsun) dari bulan Ogos hingga akhir bulan Februari untuk memeriksa kesan variasi perubahan bermusim terhadap kualiti sistem penuaian air hujan dan membandingkannya dengan Kualiti Standard Air Minum Malaysia dan piawaian kualiti air Pertubuhan Kesihatan Sedunia. Parameter-parameter fisiokimia yang diukur semasa tempoh kajian adalah suhu, pH, alkali, kekeruhan, kekonduksian elektrik (EC), kemasinan, jumlah pepejal terampai (TSS), jumlah pepejal terlarut (TDS), oksigen terlarut (DO), ammonia nitrogen (NH_3-N), klorida (Cl), zink (Zn), kekerasan seperti magnesium (Mg) dan kalsium (Ca). Keputusan menunjukkan bahawa kebanyakan parameter fisiokimia berbeza-beza semasa variasi monsun bermusim dengan nilai pH berbeza dari 5.95- 6.57 mg/L semasa musim pra monsun dan musim monsun. Nilai alkali didapati berbeza dari 10.77- 12.12 mg/L, manakala nilai kemasinan tidak terjejas oleh perubahan bermusim. Nilai TDS bervariasi dari 45.26-47.01 mg/L. Nilai TSS terendah adalah pada pasca monsun 0.92 mg/L manakala nilai tertinggi adalah pada musim monsun 1.05 mg/L. DO adalah 7.11 mg/L dalam pra monsun, 7.29 mg/L semasa monsun dan 7.53 mg/L semasa pasca monsun. Cl berbeza daripada maksimum 0.3mg/L semasa pra-monsun dan 0.07mg/L semasa monsun manakala nilai terendah adalah semasa pasca monsun (0.06 mg/L). Nilai Zn bervariasi dari 0.05-0.06 mg/L. Nilai NH_3-N adalah tertinggi (0.13 mg/L) semasa pasca monsun manakala terendah semasa monsun (0.03 mg/L) dan 0.12 mg/L semasa pra monsun. Nilai purata magnesium bervariasi dari 0.44-1.03 mg/L manakala kalsium mempunyai nilai tertinggi semasa pra-monsun (1.02 mg/L) dan terendah semasa pasca monsun (0.57 mg/L). Nilai P adalah di bawah 0.05 dan ini menunjukkan kesan variasi ketara musim tengkujuh pada parameter fizikokimia. Kualiti air hujan mikrobiologi dinilai semasa perubahan bermusim bagi kedua-dua bakteria terkenal iaitu Escherichia coli (*E. coli)* dan jumlah coliform kerana hasilnya menunjukkan perubahan ketara dalam kualiti air mikrobiologi semasa perubahan bermusim dan julat jumlah coliform adalah 35.8- 616 MPN / 100 mL manakala E. coli adalah 0-16.3 MPN / 100 mL. Secara keseluruhannya, parameter-parameter fizikokimia hasil sampel air hujan adalah dalam Standard Kualiti Air Minum Malaysia dan Pertubuhan Kesihatan Sedunia untuk spesifikasi air minum. Walau bagaimanapun, hasil parameter analisis mikrobiologi menunjukkan bahawa bilangan bakteria penunjuk yang terdapat dalam sampel air hujan melebihi piawaian kualiti air minuman tertentu dan sampel air hujan dicemari dengan kedua-dua bakteria *E. coli* dan jumlah coliform. Rawatan digunakan bagi menghilangkan pencemaran bakteria daripada sistem penuaian air dengan dos yang berbeza dan masa hubungan tertentu untuk mendapatkan dos yang dijalankan 4.0 mg/L yang mematuhi batasan bakteria yang berkesan dan untuk melaksanakan konsepsi air hujan yang dituai sebagai sumber alternatif untuk kegunaan domestik.

ABSTRACT

Rainwater harvesting system (RWH) refers to the collection and storage of rainwater for potable and non-potable use. This study carried out the quality assessment of rainwater harvesting system in Universiti Malaysia Pahang, Gambang, a small district of Pahang state for both physicochemical and microbiological characteristics to address the potential use of harvested rainwater as an alternative drinking water supply in rural areas. Rainwater samples were collected from rainwater harvesting system (WASRA), Water System for Rural Area on a weekly basis during three time intervals or which known as southeast monsoon season (pre-monsoon, monsoon and post monsoon), starting from end of August until end of February to check the effect of variation of monsoon seasonal changes on rainwater harvesting system quality and comparing it to Malaysian Drinking Water Quality Standards and World Health Organization water quality standards. Physicochemical parameters were measured during study period are temperature, pH, alkalinity, turbidity, electrical conductivity (EC), salinity, total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), ammonia nitrogen (NH_3-N), Chloride (Cl), zinc (Zn), hardness as magnesium (Mg) and calcium (Ca). The results showed that most of the physicochemical parameters varied during monsoon seasonal variation as pH mean values varied from 5.95- 6.57 mg/L during pre-monsoon and monsoon season. Alkalinity values were varied from10.77- 12.12 mg/L, while salinity values never affected by seasonal changes. TDS values varied from 45.26-47.01 mg/L. The lowest TSS value was in post monsoon (0.92 mg/L) while the highest value was in monsoon (1.05 mg/L). DO was (7.11mg/L) in pre-monsoon, (7.29 mg/L) in monsoon) and (7.53 mg/L) during post-monsoon. Cl varied from 0.30-0.07mg/L during monsoon seasonal changes and the lowest value was during post-monsoon (0.06 mg/L). Zn values varied from 0.05-0.06 mg/L. NH_3-N value was the highest (0.13mg/L) during post monsoon while the lowest during monsoon (0.03mg/L) and 0.12mg/L during pre-monsoon. Magnesium mean values varied from 0.44- 1.03 mg/L while calcium was the highest values during the pre-monsoon (1.02 mg/L) and the lowest during the post-monsoon (0.57) mg/L. The P values were below 0.05 and that shows a variation effect of monsoon season on the physicochemical parameters. Microbiological rainwater quality was assessed during monsoon seasonal changes for both widely well-known bacteria of *Escherichia coli (E. coli)* and total coliform as the results showed a significant variation in microbiological water quality during seasonal changes and the range of total coliform was 35.8- 616 MPN/100 mL and ($P < 0.001$) while *E. coli* range was 0-16.3 MPN/100 mL and the ($P < 0.001$). In general, the physicochemical parameters of the rainwater samples results were within the Malaysian Drinking Water Quality Standards and World Health Organization for drinking water requirements. The microbiological parameters results were above the drinking water quality standards and the rainwater samples were contaminated with both bacteria of *E. coli* and total coliform. A proper treatment was applied to remove the bacteria contamination by using affordable treatment of sodium hypochlorite solution with specific contact time and different doses to maintain the optimum dose of 4.0 mg/L that complies with the limits to provide an effective removal of bacteria and to apply the concept of alternative water source for domestic use in rural areas.

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CT	Contact Time
FAC	Free Available Chlorine
TC	Total Chlorine
FC	Free Chlorine
CC	Combined Chlorine
MPN	Most Probable Number
NTU	Nephelometric Turbidity Unit
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
DO	Dissolved Oxygen
TA	Total Alkalinity
NH_3-N	Nitrogen Ammonia
EC	Electrical Conductivity
UV	Ultraviolet
SODIS	Solar Disinfection
DPD	(N, - diethyl-P- phenylenediamine)
WASRA	Water System for Rural Area
RWH	Rainwater Harvesting
WHO	World Health Organization
MDWQS	Malaysia Drinking Water Quality Standards
USEPA	United States Environmental Protection Agency
AWWA	American Water Works Association

CHAPTER 1

INTRODUCTION

1.1 Background

Water is universally considered one of the most influential natural resources, if not the most valuable of all and it is the most essential commodity to the life survival (Shiva, 2016). Earth’s surface is covered with over than 70% of water and undoubtedly it is the most precious natural resources of our planet which is set an evolution of life and a crucial ingredient of life today (Gleick, 2014). There is no other resource that affects economy, human life and environmental health like water and it has been accorded as a highly priority in the global development agenda (Bergstorm & Randall, 2016). Rainwater water harvesting system concept had been practiced long time ago back 4000 years as ancient societies have developed different ways to collect rainwater such as cisterns or reservoirs construction in various areas (Mays et al. 2013). Rainwater has recently considered as an important alternative source of fresh water for both potable and non-potable use in many countries especially for far rural areas and within the increasing of world population, the increasing demand of fresh water supply and the effect of climate change that is causing a stress and water shortage in many parts of the world (Mo et al. 2014).

Malaysia as a developing nation started the implementation of harvested rainwater system in urban areas as a beginning of towards sustainability and to be used as an alternative water supply for domestic purposes especially after the drought incident that occurred in Klang valley in march 1998 (Ayob & Rahmat, 2017). Therefore, the Ministry of Housing and Local Government has introduced the guidelines of installing a rainwater collection and utilization system in 1999 and considered as the initial phase of the rainwater policy in Malaysia to help reduce the water stress during emergencies and to be used as an alternative water supply in urban and rural areas (NAHRIM, 2014).

Rainwater harvesting system refers to the collection of rainwater runoff throughout a system that could assist in the provision of water directly to household for drinking and hygiene as well (Kostyla et al. 2015). Rainwater harvesting system is considered as a clean water supply. However, in many cases the physicochemical and microbiological quality do not meet the water quality standards guidelines therefore the shortage of a good water quality could be loaded with health problems for the community (WHO, 2011). There are many reasons for poor access to safe clean drinking water but the main one is the inability to finance adequate infrastructures. In support of vision of 2020 (towards achieving developed nation status), water resources will be conserved and manageable in Malaysia to ensure satisfactory and safe drinking water for all (Cosgrove & Rijsberman, 2014). Therefore, in 1998 and after the water crises that accrued in Klang valley, the Malaysian Government decided to implement rainwater harvesting (RWH) guidelines installation system through the Ministry Housing and Local Government (MHLG) that is circulated letters of installation of rainwater harvesting system in new buildings in Malaysia and following this the Ministry of Natural Resources and Environment (MNE) and through the Department of Irrigation and Drainage (DID) published rainwater harvesting system guidebook in 1999 (Hafizi Md Lani et al. 2018). Concerning the quality of harvested rainwater in Gambang as an alternative water resource for drinking and domestic purposes use, a physicochemical and microbiological study was conducted to monitor the quality of rainwater harvesting system over the monsoon seasonal change to determine the rainwater contamination levels and conducting the proper treatment by using sodium hypochlorite solution with a certain dose for household usage to ensure that rainwater is safe to consume.

1.2 Problem Statement

In the new global development and within the constantly increasing population, fresh water sacristy has becoming a fundamental issue for sustainability development and as the expectation of water withdrawal is growing by 10- 12 % every 10 years to reach about 5, 240 Km^3 and water consumption will keep increasing by 2025 (UNESCO, 2008). The population growth has direct influence on the water supply demand rates, for example, worldwide water demand has increased six folds between 1990 and 1995 while the population was only doubled and the demand of the agricultural sector is almost 70% of the total demand and the rate of the growth in the urban area is about four times that of the rural areas (Cosgrove & Rijsberman, 2014).

Malaysia is a tropical country and located in South-East Asia, and it belongs to a tropical climate regime and the average temperature throughout the year ranges from 20 ºC to 30 ºC (Barrow, 2016). The main rainy season runs between November and March (Northeast Monsoon Season), and Peninsular Malaysia receives rainfall on the average of 3000 mm while East Malaysia receives about 5,080 mm as annual average rainfall (Salimun et al. 2014). Since the first (El Nino phenomenon in 1997), the climate has unexpectedly changed, even in tropical humid Malaysia where rainfall is abundant but water fluctuations due to a lack of rainfall happened in the 1998 and caused severe drought which brought unpleasant water supply disruption to Klang Velley for 1.8 million residents.

Since this incident happened and following this water crisis, the Minster of Housing and Local Government on 7 May 1998 has expressed the Government’s Interest to houses and new buildings to be designed for rainwater collecting system (Department of Irrigation and Drainage, 2014). The Ministry of Housing and Local Government (MHLG) with cooperation of Ministry of Environment and Department of Irrigation and drainage (DID) has produced a guideline of Installing a Rainwater Collection and Utilization System in Malaysia (NAHRIM, 2014).

The nation has suffered of water shortages and water quality problem and various measures have been taken by the government to address water issues but in spite of these quantity and quality of drinking water is still one of the main concerns of Malaysian consumers today (Abdulsalam et al. 2012). Therefore, rainfall considered one of the alternative and sustainable water resources to solve and reduce the impact of water shortage problems particularly in developing countries and far remote rural areas that where people are still without access to safe drinking water (Mwamila et al. 2016). According UNICEF, more than 1.5 billion people in developing nations are still without access to safe drinking water and about 663 million people globally worldwide still using unimproved drinking water sources and as shown in Figure 1.1 (UNICEF, 2015).

Figure 1.1 Population Without Access to Improved Source of Safe Drinking Water in 2015 Source: UNICEF (2015)

Although there is commonly concept that is harvested rainwater is safe to drink but there are many numerous studies have implicated chemical and fecal matter as the major source of rainwater contamination (Ahmed et al. 2011). The possible sources of chemical contamination can result from emission from industrial pollution in urban areas and agriculture activities in rural areas (Fetter et al. 2017). Fecal contamination in stored rainwater can be result from birds and small mammals, such as rats, which have access to the roof tops. In addition, other contaminants of harvested rainwater could include dust, leaves, insect repellents and (Waso et al. 2016). Therefore, an assessment study was applied for Water System in Rural Area (WASRA) during (pre-monsoon, monsoon and post monsoon season) to guarantee that harvested rainwater meets the guidelines of drinking water standards in both chemical and microbial quality. Chlorination considered a suitable and affordable water sanitation method using sodium hypochlorite solution to remove the microbiological contamination from the rainwater harvesting system to decrease the risks of water borne diseases and also to determine the optimum chlorine dose to eliminate bacteria contamination in drinking water within water standards guidelines.

1.3 Objectives of the Study

The main aim of this study is to provide safe drinking water in far rural areas using rainwater harvesting system, the following objectives have been set as follows:

i. To investigate the seasonal variation of physicochemical and biological characteristics of harvested rainwater in Gambang area.

ii. To assess the suitability of harvested rainwater for domestic and drinking purposes based on World Health Organization (WHO) and Malaysian Drinking Water Quality Standards (MDWQS).

iii. To assess the effectiveness of using sodium hypochlorite solution in treating harvested rain water.

1.4 Scope of the Study

The scope of this study covered the research about the quality of harvested rain water in Gambang where the experiment was conducted. The work was divided into two parts, the first part was to examine the physicochemical and microbiological parameters for the rainwater harvesting system and to assess the variation of the physicochemical and microbiological parameter of the rainwater during the seasonal monsoon changes and how it affects the quality of rainwater harvesting system during 6 months' period of time. The activities were carried out in Gambang, WASRA rainwater harvesting system and a total of 200 samples of rainwater were collected weekly from top and bottom of the rainwater tank and all samples were examined in the Environmental Laboratory of Universiti Malaysia Pahang. The second part was to figure out how suitable harvested rainwater for drinking purposes by assessing the microbiological quality which indicated heavily contamination of the rainwater system thus a proper treatment was applied by using sodium hypochlorite solution with different six doses (1.5, 2.5, 3.5, 4, 4.5, 5) mg/L within six reaction period time of (0.5, 1, 2, 4, 8, 24) hours to determine the free chlorine residuals values not less than 0.2 mg/L after 24 hours reaction time so that to ensure no re-contamination of bacteria may happened again and not more than 2 mg/L after 0.5 hour reaction time to make sure the taste and odder of harvested rainwater acceptable to consumers. A total of 50 trails of chlorine dosing were conducted to specify the optimum dosage through the experimental design and to study the behaviour of chlorine solution reaction with ammonia nitrogen and pH within specific temperature to maintain safe drinking water for domestic use purposes.

1.5 Significance of the Study

The study significance is to assess the seasonal variation effect on the physicochemical and microbiological quality of harvested rainwater and mainly the microbiological pollution during seasonal variation and evaluating the microbial quality during that variation period and comparing the results to Malaysian Drinking Water Quality Standards (MDWQS) and World Health Organization (WHO). The second part is to determine the optimum dose of sodium hypochlorite solution that should be added to harvested rainwater to maintain free chlorine residuals that provide an effective sanitation process to remove the bacteria contamination and maintain results within the water standards guidelines and to achieve the conception of an alternative water supply for domestic use purposes particularly for far rural areas.

CHAPTER 2

LITRATURE REVIEW

2.1 Introduction

This chapter provides a review and a definition of rainwater harvesting history and rainwater quality locally and internationally. It covers the concept and components of the rainwater harvesting system including the background and elements, physicochemical and microbiological contamination, factors affecting the quality of rainwater harvesting system, the importance of implantation of the rainwater harvesting as an alternative water resource for domestic purposes and previous studies inside Malaysia and globally. Also through this chapter the discussion and importance of rainwater harvesting system treatment and disinfection methods that is focusing on chlorination concept, history and reactions with water.

2.2 History of Rain Water Harvesting

The rainwater harvesting system (RWH) has been practiced for a long thousand years (Ahmed et al. 2011). By using simple techniques such as ponds and artificial reservoirs, those old systems only act to be used for acquiring and keeping the rainwater which is from the rooftops, land surfaces or rock catchment (Abbasi & Abbasi, 2011).

With the advancement of technology, these systems have been implemented days by days to get the effective results towards better environment and improvement of human's life. According to Helmreich and Horn (2009), there are three major forms of rainwater harvesting system (RWH) which are in situ rainwater harvesting system, external water harvesting and domestic rainwater harvesting system (Lange et al. 2012). In situ rainwater harvesting system will gather the rainwater falls on the surface and will be store in the soil while the domestic rainwater harvesting system could collect the rainwater from the roof and streets (Zaidon, 2014). Rain Water Harvesting system has a low impact on development practice that can serve as a primary or supplementary water source. Rain water harvesting practice involves capture, diversion and storage of rainwater harvesting (RWH) for future use (Yosef & Asmamaw, 2015).

Rainwater harvesting is listed as a source of domestic water supply called domestic rainwater harvesting (DRWH), practiced both in rural and urban areas from ancient times (Essendi & Madise, 2014). This is still applying formally and none formally. Formally means permanent storage systems while none formally means not to establish a storage, but only to put pots under roof edges (Basinger et al. 2010). Rain Water Harvesting can help alleviate demands on public water supply systems and promote better practices in the public (Sultan et al. 2016). The Rain Water Harvesting adoption varies from one place to another due to the public awareness such as legislative, technical and financial support toward this kind of practice (Lim & Jaing, 2013). The World Health Organization (WHO) proposed the use of RWH as safe potable water after applying appropriate treatment (WHO, 2011).

2.3 An Overview of Rainwater Harvesting System in Malaysia

Rainwater harvesting system for utilization and domestic use has been as a potential alternative water resource in Malaysia for solving the problems of water shortage in many places (Ismail & Manaf, 2013). Due to the rapid urbanization and after the drought incident that has occurred in 1998 in Kula Lumpur, the National Hydraulic Research Institute of Malaysia (NAHRIM) and Department of Irrigation and Drainage (DID) have started several rainwater harvesting system projects around the country (NAHRIM, 2014). Rainwater harvesting system was included in the National Urbanization Policy number 18 that has been produced by the town and Country Department (Sultan et al. 2016). In the year of 1999, officially the guidelines for installing the rainwater collection and urbanization system was introduced an initial phase of rainwater harvesting policy in Malaysia as the aim of this system is to provide a convenient buffer in times of emergency or a shortfall in water supply (MHLG, 2008).

Five years later after introducing the Guideline by the Ministry of Housing and Local Government prepared another documents to the National Water Resources Council to encourage government buildings to install rainwater collection and utilization system (NAHRIM, 2014). In March 2006 was the most encouraging and successful development of rainwater harvesting system in Malaysia after the announcement by the government to give a full support to the rainwater harvesting system installation as a good and right step towards more sustainability development in Malaysia (Department of Irrigation and Drainage, 2014). Therefore, the government has finally realised that if rainwater harvesting system become a mandatory step to install in public and local buildings there will be less water crises in Malaysia (MHLG, 2008). The details about locations and years of rainwater harvesting system projects in Malaysia are given in Table 2.1.

Table 2.1 Locations and year of rainwater harvesting system projects in Malaysia (Source: Department of Irrigation and Drainage, 2014)

Location and type of the project	**Year**
Selangor, Zoo Negara, Hulu Kelang, underground HDPE tank	2010
JPS (M&E) Kuantan, Pahang Darul Makmur. underground tank	2010
JPS Daerah Bera, Pahang, underground pipe package	2010
Kuala Lampur, JPS Headquarters, above ground HDPE tank	2010
WASRA, Pahang, Gamabng, above ground HDPE tank	2010 up to date
Kedah, JPS Langkawi, Kedah, above ground HDPE tank	2011
15 Buffalo Park, Langkawi, Kedah, above ground HDPE tank	2011
Sabah, Sandakan Municipal Council, underground HDPE tank	2012
Kelantan, Kota Bharu Municipal Council, above ground HDPE tank	2013
Perak, Institute Tanah dan Ukur Negara, Tanjung Malim, above ground HDPE tank	2013
Johor, Housing – Taman Rebana, above HDPE tank	2014
Terengganu JPS, Dungu, underground tank	2014

HDPE: High Density Polyethylene

2.4 Definition and Components of Rainwater Harvesting System

The water harvesting system term is the process of collecting and storing water from the area that has been treated to increase the precipitation runoff (Domenech & Sauri, 2011). A rainwater harvesting system is defined as the complete facility for collecting storing and treating system of precipitation runoff (Fernandes et al. 2015).

The components of rainwater harvesting system used in the study is showing in the following fundamental process diagram as demonstrated in the Figure 2.1.

Figure 2.1 Flowchart demonstrates fundamental rainwater harvesting system (modified from Dobrowsky et al. 2014)

Rainwater harvesting systems shares a number of common components (Hanson & Vogel, 2014) as the following:

i. A catchment area from which runoff is collected, e.g., a roof surface.
ii. Piping system to transfer water from catchment surface to a storage tank.
iii. A reservoir where water is stored until used.
iv. A treatment system for treating rainwater harvesting system
v. A pump to extract the rainwater from the reservoir.
vi.

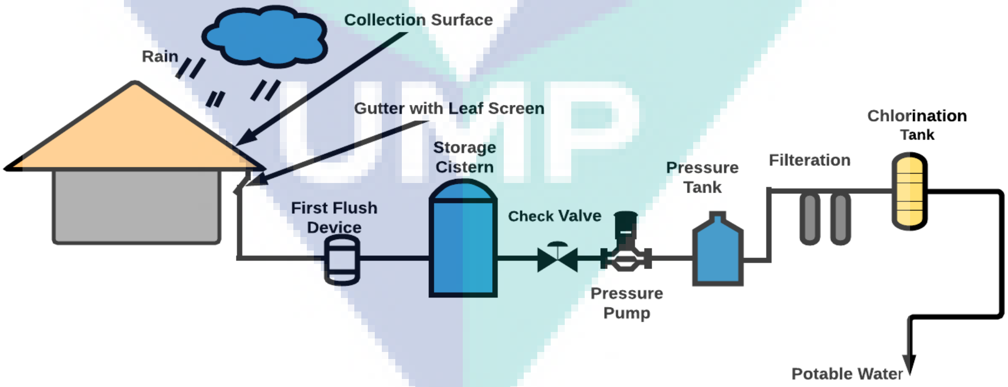

Figure 2.2 Schematic diagram of rainwater harvesting system for domestic purposes (Modified from Hanson & Vogel, 2014)

2.5 Rainwater Water Quality

The World Health Organization acknowledged that drinking water ought to contain no harmful concentrations of chemicals or pathogenic micro-organisms, and it is also should be perfectly aesthetically fair regarding to appearance, taste and odder (WHO, 2011). The visual qualities of appearance, taste and odder are commonly the characteristics by which the community judges water quality. Though, the absence of any unpleasant qualities does not assurance water safety. Therefore, the protection of water, in public health terms, is determined by its bacteriological, physical, chemical and radiological quality (Lee et al. 2012).

2.5.1 Physicochemical Pollution

Physical pollutants are mostly due to dry removal on the surface catchment. One of the physical pollutants to be measured is turbidity that is used to assess the physical contamination and it imitates the amount of slight solid particles such as mud, organic matter and biological material that is suspended in the water sample. These particles settle with the degree of clarity or cloudiness (turbidity) associated to the amount of particles that is remaining suspended. The maximum level allowed of turbidity in drinking water is 5 NTU; yet, the idyllic is 1 NTU or lower (NHMRC, 2011). However, unfiltered water as natural rainwater, has a turbidity level of 1 – 65 NTU (Dobrowesky et al. 2014). Available studies on harvested rainwater have stated variability in turbidity levels with all most samples being within the range for drinkable water systems while some exceeded 5 NTU (Despins et al. 2009).

While Chemical pollution could be due to wet deposition – presence of atmospheric gases, insect repellent, waste gases from industry and gas emission by automobile; the rainwater reaction with the system mechanisms – catchment surface, drainage and storage tank to produce metallic ions; and the materials of plants creating soluble organic compounds (Tas, 2013). Anywhere rainwater tanks are plumbed into the domestic, the slightly acidic pH and absence of buffering capacity may lead to a leakage of metals into the pipes. Leakage of the metals from catchment and materials of the tank may also occur (Wei et al. 2014).

The metals that were found in the rainwater tanks contain but are not limited to lead, copper, zinc, iron, cadmium, aluminum, arsenic, mercury and nickel (Förstner &Wittmana, 2012). This argument focuses on metallic pollution of rainwater and limits itself to aluminum, zinc, lead and copper which are some of the most frequently isolated metals in relative to rainwater supplies (Qiang et al. 2014).

There are no health guidelines have been fixed for aluminium and zinc as less than 2% of drinking water contributes of the total daily consumption of aluminium with less than 0.3 – 0.4% of the aluminium in drinking water being absorbed by the body (Gosh et al. 2013). Aluminium causes aesthetic problems as a result of post-flocculation of disinfected tap water, hence it has been recommended that the concentration of acid-soluble aluminium in drinking water should be less than 0.2 mg/L (Liao et al. 2013). The maximum suggested aesthetic level for zinc has been set at 3 mg/L since taste problems can occur if the concentration in drinking water exceeds this limit. Higher levels of zinc impart undesirable taste and a cloudy appearance to the water (Buragohain, 2010).

The presence of heavy metals in harvested rainwater system such as lead can cause a health risk issues since lead can increase in the human body and it depends on the duration and level of exposure. Lead also can cause a severe damage to the nervous system especially in babies and young children and can cause harm to kidney, digestive system and joints (Addea, 2013). The Australian Drinking Water Guidelines and WHO guidelines therefore state that the limit of lead should be not more than 0.01 mg/L (WHO, 2011).

While copper is essential to human life but can cause anemia, liver and kidney destruction, stomach and intestinal irritation if consumed in high doses (Ashish, Neeti & Himanshu, 2013). For children, high levels consumption of copper can lead to the risk of intoxication as a result of undeveloped copper metabolism, consequently high levels of copper in harvested rainwater may be a possible health risk if guideline value of 2 mg/L is exceeded (Omur & Dietrich, 2011). The details of previous studies of physicochemical parameters are shown in Table 2.2.

Table 2.2 Previous studies of physicochemical parameters

Author	Measurements of physicochemical parameters	Name of Journal
Mohammed et al. 2007	pH, Turbidity, BOD, COD, TDS, TSS, Hardness, Lead	Proceedings of the colloquium on rainwater utilization, Putrajaya
Chi-Ani et al. 2009	pH, Turbidity, Zinc, Lead Manganese	European Journal of Scientific Research
Schets et al. 2010	pH, Turbidity, Copper Lead, Manganese, Zinc	Journal of Water and Health
Daoud et al. 2011	Nitrite, Copper, Lead Turbidity, pH, Salinity	Journal of Water and Health
Hamid & Nordin, 2011	Lead, Copper, Aluminum, Turbidity, pH, Zinc	Sustainable Energy and Environment
Van et al. 2013	Total Phosphorous, Suspended Solids, Coarse Sediment	Ecological Water Quality-Water Treatment and Reuse
De Kwaadsteniet et al. 2013	Nitrite, Ammonia, Zinc, Chloride, Calcium, pH, Turbidity, Iron	Water, Air and Soil Pollution
Tay et al. 2014	Chloride, Nitrates, Sodium, Potassium, Ammonium, Manganese	Bulletin of Environmental Contamination and Toxicology
Juliana et al. 2017	Chloride, zinc, Ammonia, Nitrite, Iron, calcium	MATEC Web of Conference, EDP Science

2.5.2 Microbiological Contamination

Fecal deposition on the surface catchment is the main source of microbiological contamination. Slight to severe gastroenteritis may be caused by abundant infectious agents, including enteric bacteria, viruses and studies have shown that the microbial quality of harvested rainwater stored in tanks can be very poor (Chapman et al. 2008). General reported levels of bacterial indicator organisms reveal the variability and susceptibility of collected rainwater to fecal contamination. In these studies, the number of tanks polluted with fecal and total coliforms ranged from 75 – 100 %, the high prevalence suggesting that roof-collected rainwater supplies represent a possible source of pathogenic microorganisms (Simmons, 2008).

Several studies have defined Salmonella and Legionella as organisms from rainwater samples of a rainwater tank (Bain et al. 2014). Whereas these organisms do not affect the aesthetic properties of the water but they may cause serious illness especially amongst people with low immune system and individuals including the elderly and children (Ahmed et al. 2011). The expected exists for the presence of pathogenic bacteria in the rainwater supply given that roof catchments and guttering are subject to pollution by bird and small animal droppings (Dobrowsky et al. 2014).

Main outbreaks of waterborne disease attributable to rainwater are occasionally reported, probably because most tanks serve only single households. Numerous studies however have reported illness linked with the consumption of rainwater (Chubaka et al. 2018). An outbreak of Salmonella in Saint Paul attributed to contamination of rainwater was reported at a Queensland construction site (Kaushik et al. 2012). Recent studies in Trinidad shows that 63 people were affected by Salmonella and organism have been isolated from the tap pipe of the rainwater tank, moreover recent study in Australia found a relation between Salmonella typhimurium and harvested rainwater and the researchers found significant bacteria type in both human fecal and rainwater samples that is related as a source of illness and outbreaks endorsed to campylobacter (Franklin et al. 2009).

Control case studies showed a strong relation between disease and consumption of harvested rainwater. Generally, the outbreaks accredited to Campylobacter and Salmonella seem to have been caused by fecal contamination from surface roof which caused by birds and animals or by animal’s access to tanks (Dean & Hunter, 2012). Table 2.3 shows the microbiological indicator of bacteria presence in harvested rainwater from previous studies adapted from De Kwaadsteniet et al. (2013).

Table 2.3 Microbiological indicator of bacteria presence in harvested rainwater from previous studies (CFU/100mL**)**

Country	Total bacteria	Total coliform	Fecal coliform	*E.coli*	Reference
Malaysia	N/R	50	N/R	N/R	Mohammed et al. (2007)
New Zealand, rural area	N/R	56	N/R	38	Simmons et al. (2008)
Malaysia	N/R	75	58	N/R	Rahmat et al. (2008)
Australia, rural towns	N/R	47	370	24	Evans et al. (2009)
South Korea	N/R	9	72	N/R	Lee et al. (2010)
Palestine	N/R	50	89	30	Al-Salaymeh et al. (2011)
Greece, urban area	N/R	80	N/R	41	Gikas &Tsihrintzis. (2012)
Australia, rural area	N/R	58	165	18	Van et. al (2013)
Africa	N/R	100	N/R	77	Gwenzi et al. (2015)

N/R= Not recorded

2.6 Bacterial Pathogens Associated with Rainwater Harvesting System

The etiology of disease found in drinking water has changed dramatically since the early 1900s (Fu et al. 2013). While the early diseases associated with drinking water were those with a bacterial etiology, the more recent outbreaks appear to be dominated by gastrointestinal illness associated with viruses and protozoa (WHO, 2011). The following sections explains the types of pathogeneses that is causing waterborne diseases:

2.6.1 The Coliform Group

The coliform bacteria group is made up of microorganisms of biochemical definition used to classify bacteria that associated to fecal contaminants (Byappanahalli et al. 2012). The total coliforms represent the whole group, and bacteria that are multiply at 37 ^{o}C (Holmberg, 2017). The thermotolerant coliforms are bacteria that can grow at higher temperature (44.2 ^{o}C) and *E. coli* is a thermotolerant species that is especially of fecal origin (WHO, 2011).

2.6.2 Total Coliforms

The coliform bacteria indicated to a total coliforms bacterium to prevent the confusion with other types of bacteria in the group and they are not an indication of a health risk or a fecal contamination but can give a basic information on microbial water quality source (Naidoo & Olaniran, 2013). Total coliform has been long applied as a microbial m easure of drinking water quality because they are easy to detect and count in water (Odonkor & Ampofo, 2013). Conventionally total coliform was regarded as belonging to the genera Escherichia, Citrobacter, Enterobacter, and Klebsiella (Zahang et al. 2015). Because total coliform of non-fecal origin can exist in natural waters, their presence can seldom be tolerated in un piped or untreated water in the absence of more specific index parameters (WHO, 2011).

2.6.3 Thermotolerant (Fecal) Coliform

The term fecal coliforms are not correct but the correct terminology for these organisms is thermotolerant coliforms and are defined as the group of total coliforms that are able to ferment lactose at 44-45^{o}C (WHO, 2011). They comprise the genus Escherichia and to a lesser extent, species of Klebsialla, Enterobacter and Citrobacter. It is present in the faces of humans, other mammals and birds in a large number (Vilane & Dlamini, 2016).

2.6.4 *Escherichia coli*

It presents in all mammalian faces at a very high concentration and comes from humans and animals waste (Pal et al., 2016). During rainfalls, *E. coli* may be washed into rainwater tanks from contaminated catchment surfaces and can survive in water for weeks, so that it is useful as an indicator of fecal pollution of drinking water system (Shuster et al. 2013). *E. coli* meets all the criteria used for definition of both total coliform and fecal coliform and in addition, the organism can be distinguished from other fecal coliforms by the lack of urease and the presence of B-glucuronide enzymes (Mandal & Puniya, 2009). Although most strains are harmless but some strains can produce powerful toxic and can cause severe illness like a bloody diarrhoea and abdominal cramps (Croxen et al. 2013).

2.7 Pathogens and Protozoan

Various pathogenic microorganisms have been suggested as indices fecal pollution or indicators of treatment efficiency (Kitajima et al. 2014). The detection on of pathogen and enumeration of pathogen by culture methods should be detected in special laboratories (Law et al. 2015). While most of pathogens are present in low number in the environment, pathogen detection in treated water should always result further investigation and assessment of the need of urgent response (Sidhu et al. 2013).

Cryptosporidium oocysts and Giardia cysts are associated with human and animal fecal sources including amphibians, birds, and mammals (Rayan & Caccio, 2013). They can survive for very long period in the environment and are quiet resistance to treatment, they are sometimes found in treated water usually in low numbers (Trivino et al. 2016). Legionella is a type of bacterium found naturally in freshwater environments, like lakes and streams. It can become a health concern when it grows and spreads in human-made building water systems like showerheads, sinks and bath tubes (CDC, 2014)

2.8 Factors Affecting Rainwater Quality

2.8.1 Roof and Gutter Materials

Rainwater contamination may have varied with the type of roofing material, the level being higher when tiles used as a roof material. This may due to the fact that coarse surfaces such as tiles are likely to hold wind-blown dust and fecal matter that can be collected in the roof runoff (Maliva & Missimer, 2012). While galvanized iron roofing provides outstanding, smooth surfaces for the collection of rainwater, hence deposited material can be eroded off easily in the initial roof runoff. Moreover, the effect on microbial pollution, the catchment and gutter material may affect the chemical water quality. The metals leaking may occur under certain conditions, resulting in levels that may pose a potential health risk (Chakraborty, 2015).

2.8.2 Materials of the Tank and Maintenance

Tank material can affect the microbial contamination of the rainwater. Higher microbial counts are believed to be associated with dark coloured polyethylene tanks compared with light-coloured tanks since the heat absorbed by the dark colour may create a warm microenvironment in which bacteria can grow (Hemenway, 2015).

In the case of concrete tanks, high pH and dissolved solids are related with the stored water (Gikas & Tsihrintzis, 2012). Dissolved solids within the rainwater tank provide nutrients that may enable bacterial growth; however, the alkaline pH may result in microbial die-off (O'Keeffe et al. 2015).

2.8.3 Fecal Decomposition on the Catchment Surface

Small animals, such as birds, bats, lizards and possums can access the catchment surface from overhanging trees and may thus contaminate the surface with fecal matter (Ahmed at al. 2017). The presence of overhanging branches would also affect the quality of collected rainwater since they may harbour insects and cause deposition of leaves into the gutters (Cheng, 2012). Dead and decaying animals and leaves in the gutter system should therefore be removed by regular maintenance since they can cause chemical and microbial contamination of the harvested rainwater and/or accumulation of sediment in the tank that may provide nutrients for bacterial growth (Lye, 2009).

2.8.4 Use of First Flush Diverters and Leaf Litter Strainers at the Inlet Pipes to Tanks

The World Health Organization (WHO) states that to reduce the contamination of collected rainwater the first washings of the roof at the beginning of the rains should be run to waste (WHO, 2011). Installing a “first flush‟ device or other interceptor will prevent the initial roof-cleaning wash of water (20 – 25 litters) from entering tanks (Musoke, 2012). In the absence of first flush devices the initial volume of water washing from the roof enters the storage tank, and may contaminate the harvested supply with debris and fecal matter (Sánchez et al. 2015).

The first flush device therefore needs to have the capacity to collect sufficient water to be functional. The first flush device resulted in 9 – 62% reduction in bacterial load; however, the majority (55%) of the rainwater tank samples still failed to meet the guidelines for microbial contaminants (Kus, 2014). Screens and leaf control devices have also been recommended to prevent plant and other materials, insects or animals from entering the tank (Lu et al. 2012).

2.8.5 Rainfall

Harsh environmental conditions such as very fine dust in arid regions, extreme heat and torrential downpours of rain followed by long periods without rain can affect water quality (Kus, 2014). The microbiological quality of the stored rainwater was affected by rainfall events; however, no significant association was found in the study (Van et al. 2013). In addition, the collected water quality was affected by the rainfall intensity and the number of dry days preceding a rainfall event and in this study, a limited number of samples were taken over a five-month period from September to January of 2011 relating to the monsoon season in Malaysia (Beven, 2011). The effect of the dry season on harvested water quality was not investigated. More recently, wind velocity and direction influence bacterial load of harvested rainwater (Campisano et al. 2017). Since airborne microorganisms represent a significant contribution to the bacterial contamination of rainwater tanks, this finding is important in the installation of rainwater tanks at new dwellings (Chapman et al. 2008).

2.9 Advantages of Rainwater Harvesting System

There are many reasons to adopt using rainwater harvesting system and one of the main reasons is to overcome the increasing demand of water and also the global climate changes (Marlow et al. 2013). Within the increasing of population globally there are many people around the world are still lack of access to safe drinking water (WHO, 2011).

Thus rainwater harvesting system is believed to be a sustainable and an alternative water supply for consumers especially in far rural areas and during the disasters such as earth quick and floods moreover, it can reduce pressure on public water supply system and can contribute reducing cost of water treatment plants when people start depending on rainwater system as an independent water supply (Cosgrove & Loucks, 2015). In addition, rainwater quality considered to be good and need less treatment than surface water which is more beneficial to community and government by reducing the cost of operation and maintenance of water treatments facilities (Cosgrove & Rijsberman, 2014).

2.10 Rainwater Treatment System

In the developing countries, the need for an effective water treatment system is very important moreover the lack of having a clean source of safe drinking water for domestic use purposes is one of the main concerns of waterborne diseases as nearly 5000 children under the age of five years old die every year because of diarrheal diseases with an approximation of 1800 of these death cases are related to water sanitation (UNICEF, 2015; Guarner et al. 2012).

The effectiveness of any treatment system will greatly depends on the turbidity and the type of pathogens existing in the water source (Qu et al. 2013). Turbidity is measured by the concentration of solid particles suspended in water and it determined by light scattering and expressed as nephlometric turbidity units (NTU) (Rügner et al. 2013). These small particles represent organic matter, fecal matter or crashes which are micro-sized -fecal matter (Mukundan et al. 2013). The types of pathogens present in water source will also affect the type of water treatment system, for example viruses are difficult to remove by filtration as they are very minor while protozoa are known to form a cyst when they are under pressure and worms lay eggs.

Cysts and worm eggs are resistance to UV and chemical treatments as they are encapsulated by a tough cell wall (Ramirez et al. 2015). Commonly there are four types of water disinfection utilized for rainwater harvesting system which includes the following:

i. Chlorination
ii. Filtration
iii. Ultraviolet
iv. Solar disinfection (SODIS)
v. Thermal disinfection: Solar Pasteurization and boiling

2.11 Overview of Chlorine History

Chlorine was discovered first and produced in Sweden in 1744. The element was discovered by Carl Wihlelm Scheele and people at that time believed that odder from water could transmit diseases so they used chlorine to remove odder from the water (Haynes, 2014). The water initial use of chlorination dated back to 1846 when chlorine was added to water as a disinfectant at the Vienna General hospital and since then it was found to be an effective tool for devastation of many microorganisms that related with waterborne diseases, such as typhoid, cholera, dysentery, and gastro-enteritis (Van at al. 2013). With this amazing discovery, chlorine began to be approved in Belgium and Great Britain as a disinfectant for drinking water and the first use of water chlorination in United States for water supply took a place in New Jersey and extent to Canada (Lin et al. 2012). Unquestionably, chlorine and its products are the most commonly used sanitizers and their discovery has been one of the most important innovative in public health (Lee, 2013).

2.11.1 Water Disinfection by Using Chlorination

Until the late of 1970s, chlorine was practically the only disinfectant used to treat drinking water (Hunter, 2009). Chlorine considered as the most perfect disinfectant based on its proven characteristics:

i. Active against most known pathogens.
ii. Provides residuals to prevent the re-growth of bacteriological to protect the treated water through the water distribution system.
iii. Suitable for a variety range of water quality conditions.
iv. Easily to control and monitor.
v. Rational coast.

However, chlorination remains the most commonly used disinfection method so far, water system may use alternative disinfectants, including chloramine, chlorine dioxide, ozone, and ultraviolet radiation (Hunter, 2009). Lately, the providers of drinking water have faced many challenges, including:

i. Treating resistance pathogens such as Giardia and Cryptosporidium.
ii. Reducing disinfection by products.
iii. New Regulations of environmental and safety.
iv. Support Security at water treatment facilities.

2.11.2 Sodium Hypochlorite

Commercial sodium Hypochlorite (NaOCl), or liquid bleach, is manufactured by reaction elemental chlorine with sodium hydroxide. Normally, hypochlorite solutions contain from 5 to 15% available chlorine, these solutions are clear light yellow in colour, and have a strong chlorinous alkaline corrosive with odder.

The solutions contain a mixture of hypochlorous acid and chlorine monoxide). The concertation percentage used with hypochlorite is in terms of trade percent and this is different from percent by weight that takes in consideration solution’s specific gravity (White, 2010). The trade percent is as following bellow:

$$\text{Trade percent} = Clorine\ (\tfrac{g}{L}) \times 100\ /10000 \qquad 2.1$$

Each 15% solution contains (180 g/L) of chlorine; and each 10% of solution it contains (100g/L), and accordingly on.

Sodium hypochlorite is formed by reacting sodium hypo chloride with chlorine:

$$Cl_2 + NaOh \rightarrow NaOCl + NaCl + heat \qquad 2.2$$

Through this reaction, heat is generated and must be controlled to reduce the chlorate formation at the beginning and maximize constancy during the storage. Sodium hypochlorite is exposed to decay, unlike elemental chlorine. Table 2.4 shows main factors that affect hypochlorite sodium stability adapted from Barns & Sharp (2017).

Table2.4 Main factors that affect hypochlorite sodium stability

Factor	Bond	Decay Products
Concentration	Stability increase inversely with concertation	Chlorate
Temperature	Stability increases inversely with temperature	Chlorate
Metallic	Reduce Cu, Ni, Co concentrations	O_2
Impurities pH	A pH between 11.5 and 13 is best	Chlorate
UV light	Reduce light exposure	Chlorate/O_2

2.11.3 Chlorine Hydrolysis Reaction

Chlorine is a strong oxidant and can undergo considerable reaction in contact with water and other compounds. When chlorine gas (Cl_2) is added to water it dissolves according to Hennery's law and rapidly reacts with water to form hypochlorous acid (HOCl) and hydrochloride acid (HCl) is formed and as shown in the following formula below:

$$Cl_2 + H_2O \rightarrow HOCl + HCl \qquad 2.3$$

At pH levels above 4 in diluted solutions the reactions illustrated in the following Figure 2.3. When pH drops below 4, the available chlorine percentage in the form of chlorine gas increases along with the vapour pressure. For each milligram per litter (part per million) of chlorine added, 0.7-1.4 mg/L of alkalinity is consumed. At typical chlorine dose rates (1-5 mg/L), the pH of the water receiving will be reduced but buffered by the water's natural alkalinity (AWWA, 2018). When pH rises above 7.5 and at (20^o), a percentage increasing of free chlorine is in the form of hypochlorite ion. When a pH is below 7.5, then free chlorine in the form of HOCl and as shown in illustrated Figure 2.3, temperature will also impact the equilibrium and the effect is important particular at pH is between 7 and 8. This reaction is independent of concertation, it is completely adjustable, and responds immediately to pH changes (Pressman et al. 2010).

The following Figure 2.3 demonstrates the distribution of Hypochlorous/ Hypochlorite percentage versus pH value:

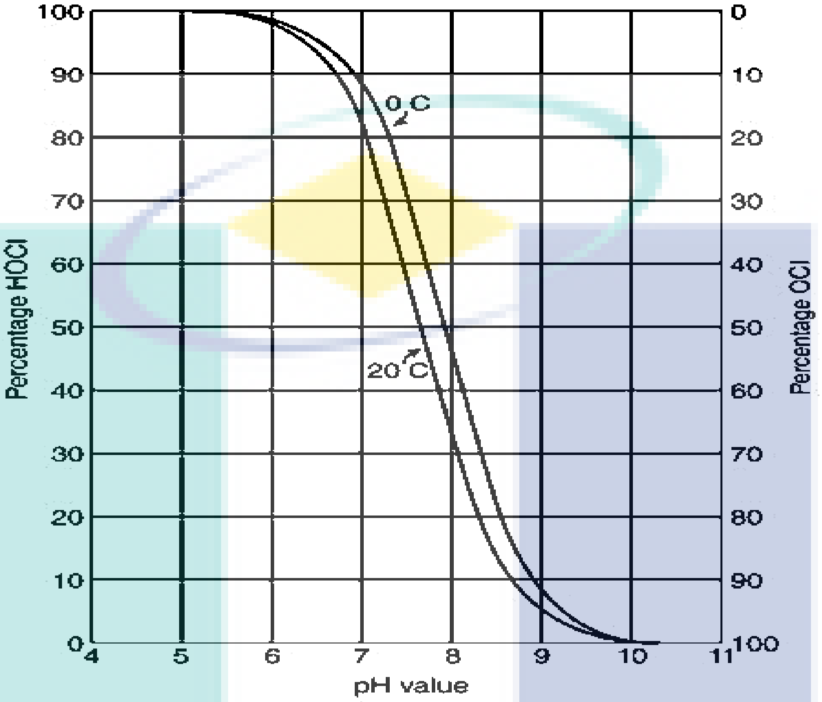

Figure 2.3 Hypochlorous/ Hypochlorite distribution versus pH Source :(White, 2010)

The formation of HOCl via the above reaction is essential because hypochlorous acid is a week acid it endures only partial separation. At pH values between 6.5 and 8.5, the above reaction is incomplete and both species are present to some degree (AWWA, 2018). The combined concentration of HOCl and OCl^{-} is known as “free chlorine residual”, (FCR). Though, these two species react quiet differently. HOCl is a very much stronger disinfectant, very strong oxidant, and more sensitive than OCl^{-}. HOCL disinfect hundreds times faster and oxidize compounds comparing to OCl^{-} that will not, but it will be consumed at a very high amount.

This active relationship that which HOCl is consumed and the remaining FCR re-equilibrium according to the relationship that is shown in Figure 2.3, OCl^{-} acts as a disinfectant buffer and adding HOCl as it is being consumed (AWWA, 2018). The chlorine rapidity of disinfection and durability of the residual is consequently affected powerfully by pH of the water that is being treated and more over to be more reactive. HOCl is neutral and can easily penetrate negatively charged bacterial surfaces and suspended particles shielding pathogens. Also chlorine may be added as a sodium hypochlorite or calcium hypochlorite (AWWA, 2018). There are obvious differences in feeding features, and hypochlorite will add alkalinity as opposed to chlorine gas consuming alkalinity, once when added to the water the residual resulting blurry from those that added by chlorine gas as shown in the following reaction formulas:

$$NaOCl + H_2O \rightarrow HOCl + NaOH \qquad 2.4$$

$$Ca(OCl)_2 + 2H_2O \rightarrow 2HOCl + Ca(OH)_2 \qquad 2.5$$

2.11.4 Chlorine Reaction with Ammonia

The chlorine ammonia reaction is one of the great significant in water chlorination process, particularly the disinfection part. When chlorine is added to water containing natural or additional ammonia, the ammonia reacts with HOCl to formulate several chloramines that, like HOCl, retain the originating capacity of chlorine. However, if the ammonia amount is too little then the effect on chlorine demand and free residuals is less obvious (AWWA, 2018).

2.11.5 Chlorine Reactions with Organic and Inorganic Oxidations

The reaction of chlorine depends on chlorine speciation as a function of pH. The different aqueous chlorine species, hypochlorous acid is the major reactive from during water treatment. For the chlorination reactions, the elementary reaction can be formulated as the following:

$$HOCl + B \ \rightarrow Products \qquad 2.6$$

Where B is an organic compound. There are other elementary reactions that have been proposed by many researchers under acidic conditions. These are the acid catalysed reactions of hypochlorous acid or Cl_2 reactions with B (Yuan et al. 2015). The following formulas show these reactions:

$$H^+ + HOCl + B \rightarrow Products \qquad 2.7$$

$$Cl_2 + B \rightarrow Products \qquad 2.8$$

Sometimes the acid catalysed reaction was associated to H_2OCl^+ species and lately the existence of H_2OCl^+ and its reactively has been strongly argued. The free chlorine speciation and reactivity in the pH range 1-12 and Cl_2 aqueous is probably the most reactive chlorine species at low pH (Sivey & Roberts, 2012).

2.11.6 Chlorine Demands

The research on chlorine demands has been related to chlorination of potable waters. Feben and Taras found a definite relationship between chlorine demand and the complicity of the organic nitrogen compounds that found in water supply of Detroit city (Blokker et al. 2014). Perssley worked on a pilot study associated the level of upgrading of the water to the chlorine to ammonia ratio required to reach breakpoint. Through the study, water should receive high levels of treatment. For example the water with lower concertation of organics present required lower Cl:NH_3-N dosage to reach the breakpoint, while all other factors were constant (Gile, 2016).

2.11.7 pH of The Water

The perfect pH for water disinfection process expected to be between 7.0 - 8.0 under ideal conditions as Palin and Presseley mentioned (Ma et al. 2016). However, no research could be found that examined the effect of significant pH variations on the reactions. Previous studies noted that the most important effect of pH on disinfection in the ranges that they investigated, pH 6.7-7.2, and as the more decrease in pH the more decrease in the reaction of as well (Zhang et al. 2015).

2.11.8 Concentration of Chlorine and Contact Time

The effectiveness of chlorination primarily depends on two main factors, concentration C and contact time T. The destruction of pathogens and organisms, often referred to as the destroy and is directly related to these two factors as the following: destroy is proportional to C× T (Hua et al. 2012). So that, if the concentration of chlorine is decreased then the contact time and they physical contact time length between chlorine and organism must be increased to ensure that the effectiveness of destroying pathogens is the same and if the chlorine concentration increases then the contact time needed to be decreased for eliminating the organisms and bacteria contamination (AWWA, 2018).

A residual of combined chlorine, which is a weak disinfectant, and requires a greater concertation, that is acting over a long period of time than is required for a free chlorine residual. Therefore, when the contact time between the point of chlorine application and the consumption of water to consumers is short, only a free chlorine residual will provide effective disinfection (Smith et al. 2014). It is important to know the contact time and the type of residual chlorine available, so that the proper concertation can be added. The following Figure 2.4 illustrates how many minutes are needed by different residual concertation to achieve 99 percent destruction of *Escherichia coli* at 2º— 6ºC. In general, a minimum free chorine residual of 0.2mg/L should be maintained at the extremities of the system distribution (AWWA, 2018).

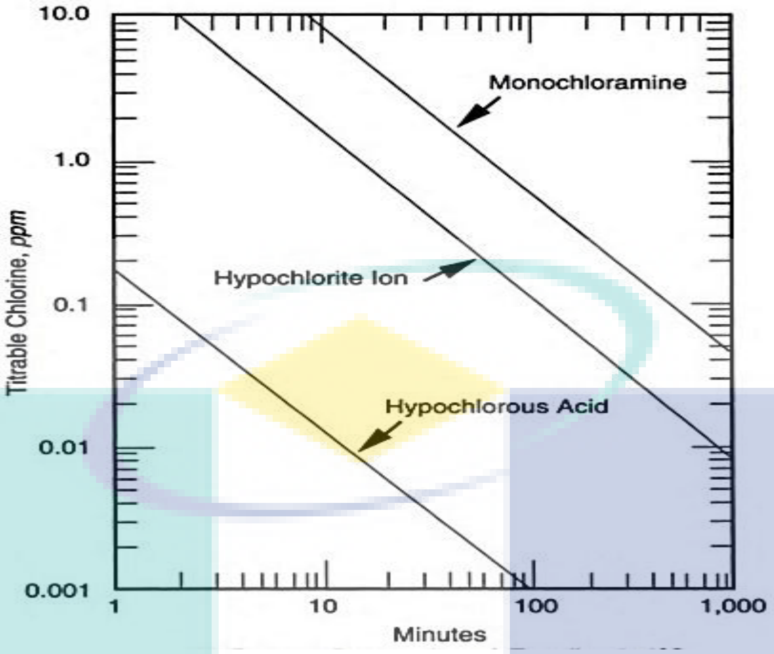

Figure 2.4 Percent destruction of *E. coli* at 2— 6ºC Source :(AWWA, 2018)

2.11.9 Temperature of the Water

The chlorine effectiveness is also related to the temperature of the water. At lower temperature, the destruction of bacteria tends to be slower. However, chlorine is more stable in cold water and the residuals will remain for longer period of time, compensating more effective at higher water temperatures and it is important to maintain water temperature records as the temperatures change seasonally, the chlorine dosage will also be needed to adjusted and the effectiveness of the combined chlorine residual is more influenced by low temperatures than that of the free chlorine (Crittenden et al. 2012).

2.11.10 Interferences Substances

Chlorine can be an effective sanitiser when it contacting with organisms that need to be eliminated. Thus, the tiny particles that cause turbidity and other suspended solids in water can block a good contact and protect the organisms. Therefore, for an effective chlorination process, turbidity must be reduced as possible by using coagulation, flocculation and filtration (Lu et al. 2016).

2.12 Analytical Methods of Chlorine Measurements

2.12.1 The Calorimetric Method (DPD)

The DPD (N, N-diethyl-p-phenylenediamine) method for residual chlorine test was original announced in 1957 (Zelanski et al. 2012). Over the years it has become the most commonly method to be used for determining free and total chlorine in water and wastewater. Hach Company presented the first chlorine test kit based on the DPD chemistry, the chemicals for the DPD reaction is shown in Figure 2.5 The DPD amine is oxidized by chlorine to two oxidation products. When pH is near to neutral, the main oxidation product is as semi-quinoid cationic compound known as a wurster's dye. This quite stable free radical species account for the magenta colour in the DPD colorimetric test. The DPD also can be further oxidized to a fairly unstable, colourless imine compound. When DPD reacts with small amounts of chlorine at a near neutral pH, the Wurster's dye is the principle oxidation product. When the level of Oxidant is too high, the development of the unstable colourless imine is favoured-resulting in apparent fading of the coloured solution (Kumar et al. 2014). The following Figure 2.5 shows the chlorine reaction products with amine DPD chemicals process:

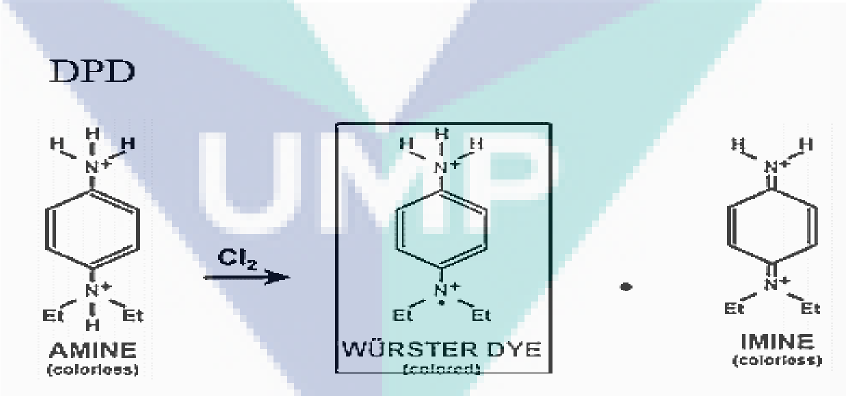

Figure 2.5 DPD Chlorine reaction products Source: (Kumar et al. 2014)

The DPD Würster dye colour has been measured photo metrically at wavelength ranging from 490 to 555 nanometres (nm) (Zarei et al. 2011). The Spectrum absorption which is shown in Figure 2.6 specifies a double peak with maximum at 512 and 533 nm.

For the maximum Sensitivity, the measurements of absorption can be made between 510 and 515 nm. Hach Company has selected 530nm as the measuring wavelength accuracy between instruments and spread out the working range of the test on some instruments (Kumar et al. 2014).

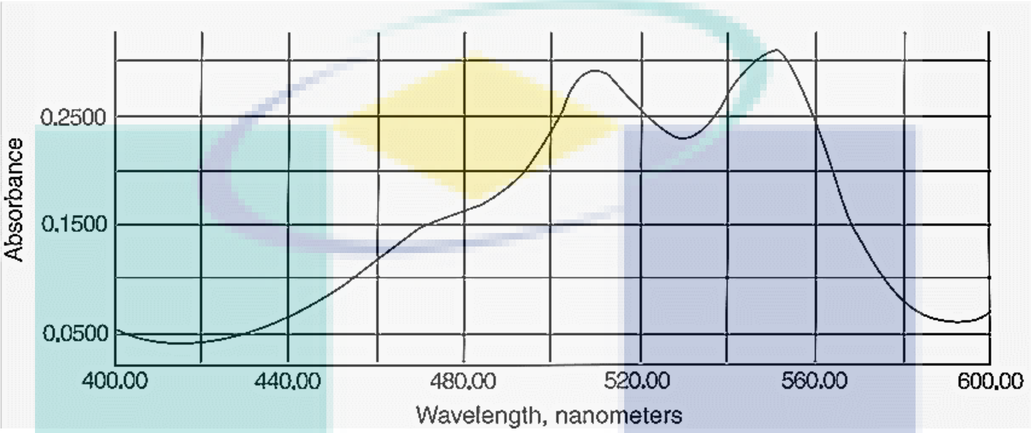

Figure 2.6 Absorption spectrum-DPD wurster's compound source: (Kumar et al. 2014)

The triiodide in turn reacts with DPD, forming the wurster's oxidation product, there is very little confirmed evidence that trichloramine species can be quantified when using iodide with DPD. In practice only a trace of iodide is required at pH 6.2- 6.5 to resolve monochloramine (APHA, 2005). Two "standard" DPD colorimetric methods generally are recognized in the international community. These are the Standard Methods 4500-Cl and International Organization for Standardization (ISO) Method 7393/2 1985. The (Iso) method has been adopted by most the members of the European Union. Both standard methods and ISO procedures call for liquid DPD reagents prepared from DPD sulphate or DPD oxalate salts. DPD liquid reagents, unstable and are subjected to oxidation from either atmospheric oxygen or dissolved oxygen presents in the preparation water.

It has been shown that the oxidation of DPD by oxygen is pH- dependent (Karthikeyan, 2016). Standard Methods and ISO procedures both use phosphate buffers to adjust the sample pH to between 6.2 and 6.5. The slightly acidic pH is preferred to quantitatively resolve the chloramine species and to minimize interferences. Phosphate buffers, however, do not work in hard or brackish water (AWWA, 2018). Calcium and manganese ions in the samples will precipitate the phosphate and destroy the buffering capacity and because aqueous phosphate solutions are excellent growth media for biological growth, highly toxic mercuric chloride is added to preserve the reagent. To overcome this unstable problem of liquid reagents Hach Company invented powder formulations to overcome the disadvantages of using liquid reagents. The DPD indicator and buffer are combined in powder form to minimize degradation by oxidation and microbial action and the DPD powder reagents from Hach company are quiet stable when protected from moisture, light and temperature, also it is recommended that both liquid and powder reagents must be stored between 10 - 25°C (Kumar et al. 2014).

2.12.2 DPD Titration Method

The DPD titration method is based on the same chemistry as the DPD calorimetric method in that DPD is oxidized by chlorine or iodine in the case of chloramines to the magenta- color then is titrated with a ferrous reducing agent to the colourless end point. The reaction chemistry is shown in Figure 2.7. Standard Methods and ISO DPD titration procedures both use the same buffer and indicator reagent formulations as those specified in the referenced DPD calorimetric methods. The ferrous iron titrate reagent that is used in the Standard Methods and ISO DPD titration methods is prepared from ferrous ammonium sulphate (APHA, 2005).

The following Figure 2.7 shows the chemistry of DPD- FAS Titration Method:

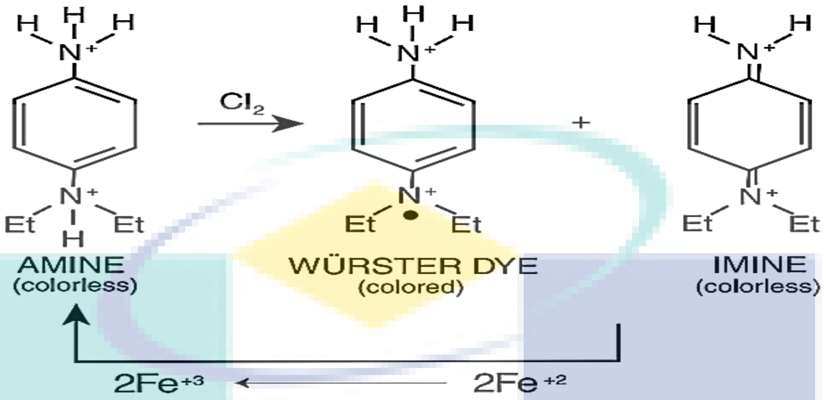

Figure 2.7 Chemistry of DPD-FAS Titration Method Source: (Kumar et al. 2014)

2.13 Summary

This chapter summarized the main concepts and definitions of rainwater harvesting system parameters, physicochemical qualities, microbiological quality of previous studies from Malaysia and other countries which is obvious the focus is on the analysis of physicochemical parameters is more likely than microbiological. However there few studies in Malaysia concerns about microbiological quality of harvested rainwater but not so expanded as referred in previous studies in Table 2.3, moreover most of the studies covers the physicochemical of harvested rainwater and the feasibility studies more than the microbiological quality studies as referred in Table 2.2 previously and to use the rainwater for non-potable use. Also there are no long term studies to show the effect of monsoon season on harvested rainwater quality (physiochemical and microbiological) and less studies covered the rainwater harvesting system treatment and go through the rainwater disinfection process for domestic purposes.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the research framework and this section will cover the research study area, sampling, materials, experimental set up about investigating and analysis of the physicochemical and microbiological quality of WASRA project for rural areas and applying the proper treatment to eliminate the microbial contamination from the harvested rainwater by applying sodium hypochlorite solution to the rainwater samples to determine the optimum chlorine dose within the specification of water guidelines and using methods approved by American Public Health Association, American Water Works Association and United States Environmental Protection Agency (APHA, AWWA & USEPA). The main purpose of the research methodology is to conduct the experiment and defining a good result that leads to achieve the main objectives of the research study, effective parameters and the method of collecting and analysing samples to maintain an integrated approach to the area of case study.

The rainwater samples were collected during seasonal changes and started from 20 of August, 2016 until 28 of February, 2017 from WASRA rainwater harvesting system in Gambang area. All samples were examined for both physicochemical and microbiological characteristics. Disinfection was applied to rainwater samples by adding sodium hypochlorite solution with specific dosages to test for free available chlorine residuals (FAC) and total chlorine residuals (TC) within a definite contact time (CT) was carried out at Uiniversiti Malaysia Pahang environmental laboratory according to the Standards Methods of Examination of Water and Wastewater (APHA, 2005) and American Water Works Association (AWWA, 2018) and United States Environmental Protection Agency (USEPA, 2006).

3.2 Research Framework

This projected study is an approach to physiochemical and microbiological charctestics of the harvested rainwater of WASRA system during seasonal change of (pre-monsoon, monsoon and post monsoon) season. Rainwater samples were contaminated with bacterai therfore a treament was applied to eliminate this contamination by using sodium hypochlorite soloution with different doses at the Environmental Labrotarty to determine the optimum chlorine dose according to the experimintal study design to ensure that harvested rainwater is clean and safe for domestic use puposes. The outline of the study is described in Figure 3.1 to provide a clear view of the experimental design approach.

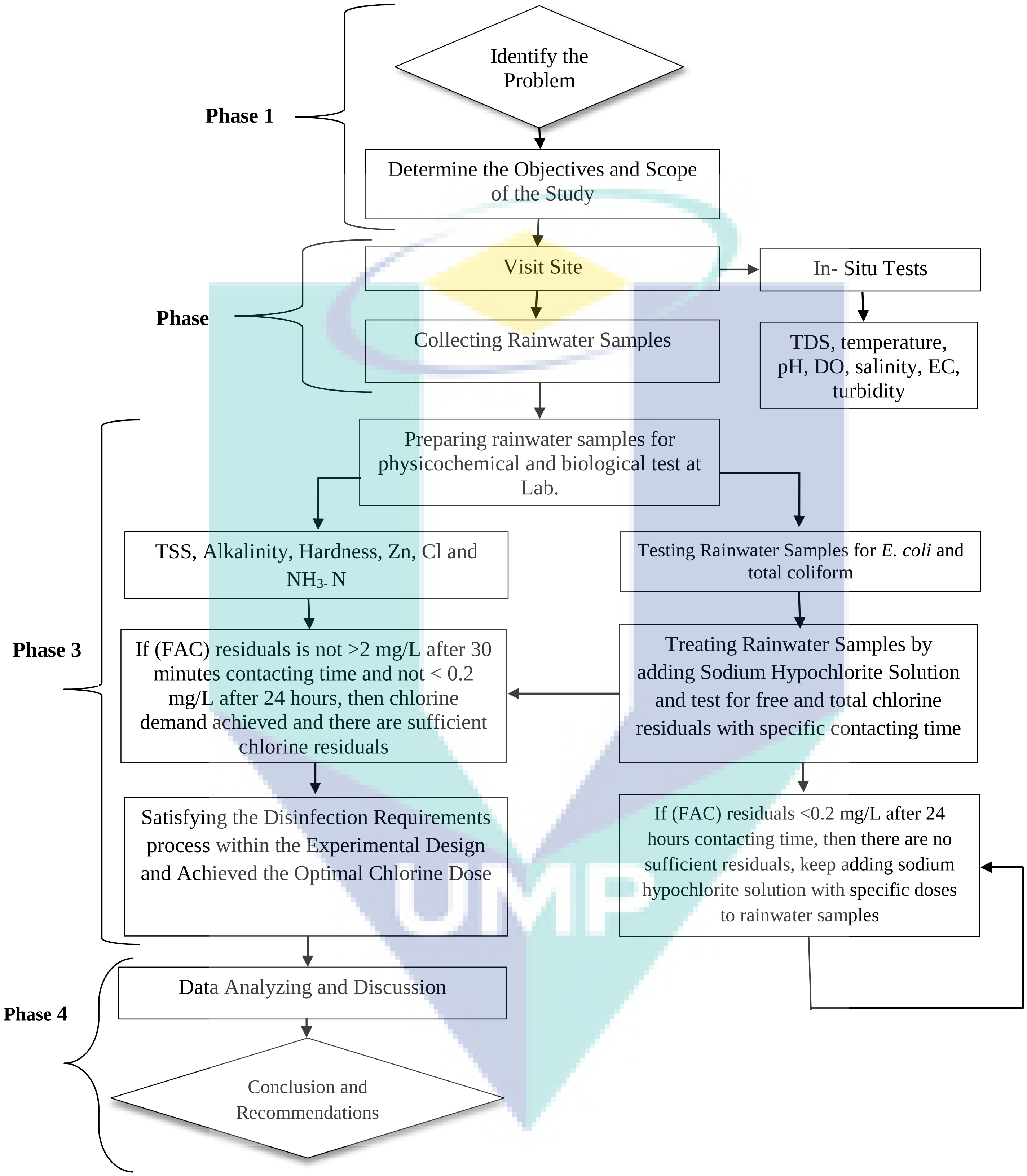

Figure 3.1 Flow chart of the experimental plan

3.3 Description of the Study Area

The study project was conducted at WASRA rainwater harvesting system at Universiti Malaysia Pahang nearby Universiti Masjid, Gambang that is located in longitudinal coordination (3^{o} 32′ 35″ N and 103^{o} 26′ 10″ E) which is a small district of Kuantan that is a big city of Pahang state in Malaysia. The average monthly rainfall is 438 mm and the temperature range is usually from 22 - 32 ^{o}C as maximum whereas the humidity varies from 62% to 96% which is known as a monsoon season that is initiated from China and north Pacific start between November and February in Malaysia (Othman et al. 2016). Figure 3.2 shows the description map of the study area.

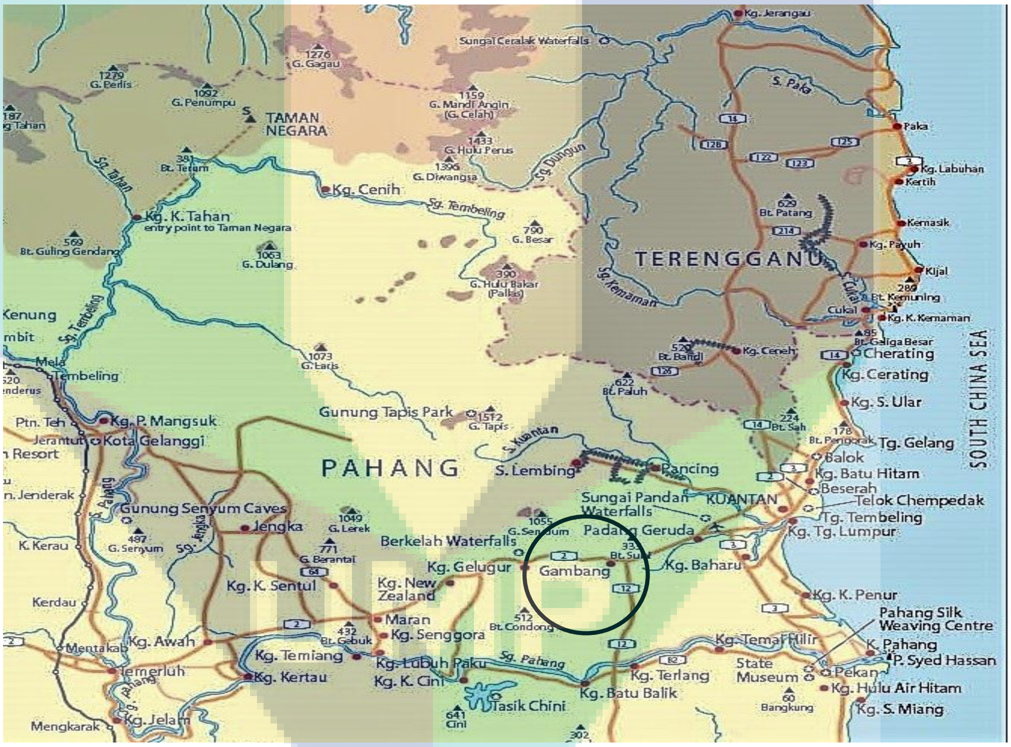

Figure 3.2 Description Map of the Study Area Source: (Official Website of Pahang)

3.4 Rainwater Sample Preparation and Collection

During sampling the following procedure was adapted:

i. In order to achieve accurate results and to minimize the sample contamination all rainwater containers were washed with distilled water and rinsed with deionized water and dried prior to sampling activity. All glass containers for microbiological analysis were washed with distilled water carefully and sterilized at university environmental laboratory preceding to use and all bottles were labelled clearly for recording.

ii. Rain water samples were collected four times on a weekly basis started from 20 of August, 2016 the pre-monsoon season until 28 of February, 2017, post monsoon season from rainwater harvesting system WASRA in Gambang and the samples were collected after each rainfall event within 24 hours' detention time in the tank and all rainwater containers were labelled according to date of collection, sampling numbers and preservation if any.

iii. Rainwater samples were collected from two collection points of the storage tank of the capacity of 1000 litter, the first one is from the top of the tank surface water and the other one is at the bottom outlet of the tank and the number of samples that drawn were two from top and two from the bottom.

iv. The collected samples placed in polyethylene bottles of 1000 mL size for physicochemical parameters analyses and sterilized glass bottles for microbiological analyses, the size of each sample is 400 mL.

v. All rainwater samples were put inside ice-box container and transported immediately to university environmental laboratory in the same day for analysing.

vi. All rainwater samples were tested for both physicochemical and microbiological parameters at Univesiti of Malaysia Pahang Environmental Laboratory by using Standard Methods for main anions, catinos and heavy metals (APHA, 2005).

vii. Sample preservation stabilized analytic concentration for a limited time, therefore samples that were not analysed in the same day of samples collection were stored in 4 °C inside the laboratory chiller and a nitric acid HNO_3 was added to samples for heavy metals analysing according to Standard Methods by American Public Health Association (APHA, 2005).

The following Figure 3.3 shows a schematic diagram of WASRA rainwater harvesting system.

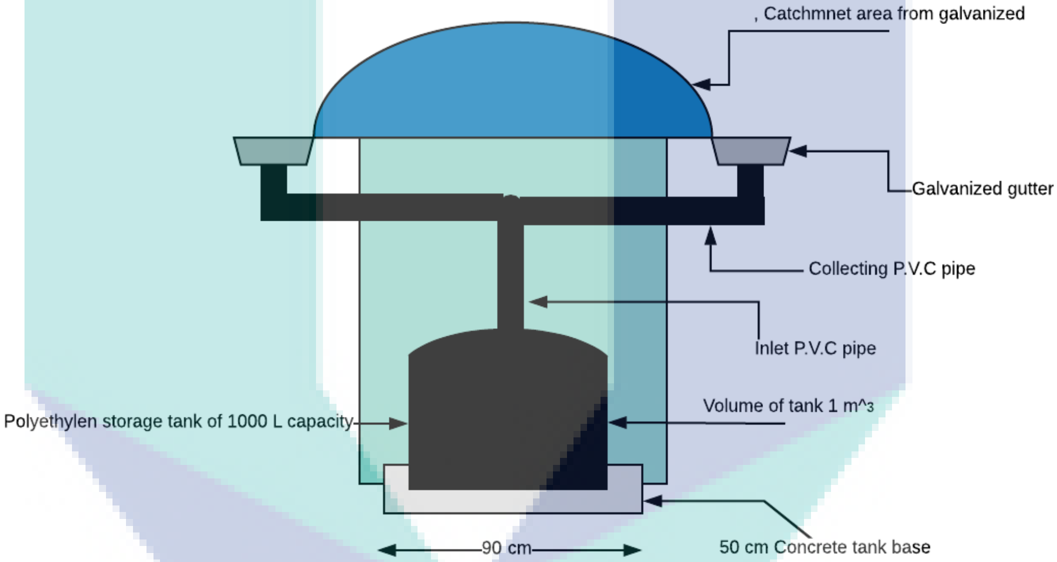

Figure 3.3 Schematic diagram of WASRA rainwater harvesting system, back view

The following Figures 3.4 and 3.5 demonstrates the rainwater storage tank and rainwater, catchment area and rainwater, gutter and rainwater collection pipes details.

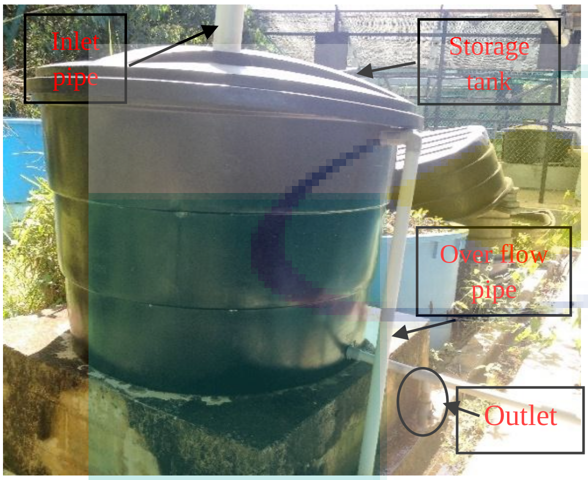

Figure 3.4 WASRA rainwater harvesting tank

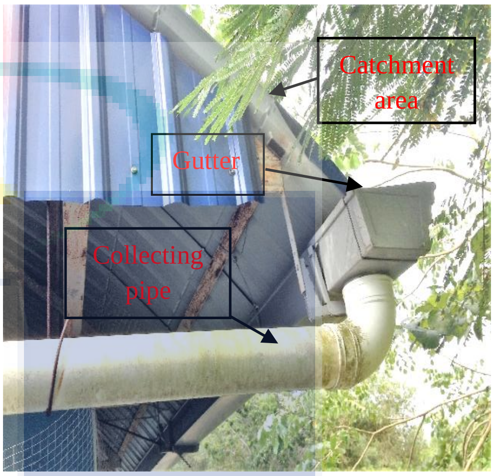

Figure 3.5 Roof collection system

3.5 Physicochemical Analysis of Rainwater Samples

Through this research study, physicochemical and microbiological rainwater parameters were carried out and analysed to determine rainwater quality. The rainwater physicochemical parameters divided into two groups, the first in-situ test was conducted for, temperature, total dissolved solids, conductivity, salinity, pH, dissolved oxygen, turbidity, while second group tested in laboratory included total suspended solids, alkalinity, hardness, zinc, chloride, ammonia nitrogen and (pH, temperature) for chlorination procedure. The microbiological analysis was performed at laboratory for the rainwater samples within 4 hours of sampling time.

All physicochemical and microbiological analyses were conducted according to Standards Methods of American Public Health Association and American Water Works Association standards (APHA, 2005; AWWA, 2018).

A quality assurance and quality control (QA/QC) plan established by following guidelines of American Public Health Association and American Water Works Association through this study for rainwater sampling and analysing both in field and at laboratory (APHA, 2005; AWWA, 2018). Duplicate water sample was conducted for each water quality parameters. Analytical quality control was ensured by blanks and standard solutions which ensured the accuracy of the results (Akpoveta et al. 2011). The analytical determination of each parameter was carried out at Environmental Laboratory of Universiti Malaysia Pahang and according to Standards Methods of Examination of Water and Waste Water and American Water Works Association (APHA, 2005; AWWA, 2018). All samples did not exceed the appropriate holding time for each parameter and duplicates with blanks were used to check the calibration and accuracy of laboratory equipment. Table 3.1 shows the Apparatus and methods of analysis of physicochemical parameters. Appendix A shows details about the experimental work at laboratory.

Table 3.1 Apparatus and Methods of Analyses of Physicochemical Parameters

Parameter	Apparatus and methods
Alkalinity	Titration apparatus, Titrimetric method
pH	HACH pH meter (sension 1) at site, Electrometric method and Mettler Toledo Electronic devise at laboratory
TDS, EC, Salinity and temperature	HACH Sension 5
DO (mg/L)	Dissolved Oxygen meter, YSI 5100
TSS (mg/L)	Total sample filtered through 1 μm glass fibre filter papered analysed for TSS. Method 2540D
Turbidity (NTU)	Hach turbidity meter, 2100P, method 2130B
Hardness (mg/L)	EDTA & EGTA, Hach method 8030, Sepectro-photometer DR-5000
Zinc (mg/L)	Hach method 8009, Zincover powder pillow, Spectrophotometer DR-5000
Chloride (mg/L)	4500 Cl^- (D), Mercuric Nitrate method, Spectrophotometer DR-
Ammonia-Nitrogen (mg/L)	5000Salicylate method 8155, Hach pillow powder, Spectrophotometer DR-5000

Alkalinity calculated by using the following equation:

$$\text{Total alkalinity (CaCO3)} = A \times N \times 50{,}000/V \qquad 3.1$$

Where V= sample volume in mL, A= volume of acid used and N normality of acid used and the normality was 0.02 N of HCl at laboratory.

3.6 Microbiological Analysis

All Samples were examined for the two widely used bacterial indicators total coliform (TC) and *Escherichia Coli (E. coli)* at the environmental laboratory and the following table 3.2 shows the Apparatus and method of analysis of *E. coli* and total coliform bacteria.

Table 3.2 Apparatus and method of analysis of E. coli and total coliform

Parameter	Apparatus and method
Total coliform and *E. coli* (MPN/100 mL)	Colilert- Technology IDEXX- Quanti- Tray 2000 model 2 X sealer and Thermolyne incubator type 142300

3.7 Experimental Set Up for Chlorine Residuals Test

Rainwater samples were prepared for chlorination process at the laboratory and through this experiment section the steps of experimental procedure for rainwater chlorination dose was explained.

3.7.1 Chlorine Solution Preparation at Laboratory

Chlorine solution was prepared at the laboratory on daily basis using a sodium hypochlorite solution with a concentration of 15% as a stock solution by diluting it in a distilled water to prepare a standard solution of 1000 mg/L. Sodium hypochlorite solution was used because it is easy to transport and use and it is economically affordable and available and effective for water disinfection.

3.7.2 Chlorine Dosing

Rainwater samples were dosed with sodium hypochlorite standard solution (1000mg/L) by using pipet at various doses as experimental designed. Rainwater samples were divided into 6 dosing categories as rainwater samples were divided into six clean glass flasks container of 1 L volume for each within laboratory temperature and pH was measured for all samples before and after chlorine dosing. Temperature was tested for all samples before and during dosing procedure and turbidity was tested for all chlorinated samples and ammonia nitrogen was measured for all rainwater samples prior and after chlorine dosing. Sodium hypochlorite standard solution NaOCl was dosed to each flask with various dosages concentration in order to produce free chlorine residuals not less than 0.2 mg/L after 24 hours' contact time and not more than 2 mg/L after 30 minutes' contact time (CDC, 2014).

The main target is to maintain the optimum sodium hypochlorite solution dosage that can sustain in water and ensure appropriate disinfection process for household and domestic purposes. During chlorine test, chlorine residuals were measured for both free available chlorine (FAC) and total chlorine (TC) for each chlorine dosage with the designed contact time for the experiment by using DPD (N, N-diethyl-p-phenylenediamine) colorimetric method at Universiti Environmental Laboratory (APHA, 2005).

3.7.3 Free Available Chlorine Residuals Measurements

Free available chlorine residuals (FAC) were conducted by suing DPD (4500-Cl G) colorimetric method that is approved by Standard Methods for Examination of Water and Waste Waters by American Public Health Association (APHA, 2005), American Water Works Association (AWWA, 2018), and approved by Environmental Protection Agency (USEPA, 2006). FAC residuals were measured for each chlorine dosage (1.5, 2.5, 3.5, 4, 4.5, 5) mg/L within the designed contact time (0.5, 1, 2, 4, 8, 24) hours by using powder pillow from Hach and spectrophotometer DR- 5000 with 530 nm wave length as these dosages were used based on trial process at laboratory. The target of FAC residuals is not less than 0.2 mg/L at 24 hours contact time and not more than 2 mg/L at 30 minutes' contact time and to determine how much sodium hypochlorite dosage should be added to rainwater that is stored and used for drinking purposes. Hence, FAC residuals are the most important one for disinfection and killing germs through disinfection process as the recommendation of World Health Organization (WHO) and Centre for Diseases Control and Prevention (CDC) for a safe drinking water use for domestic use (CDC, 2014). pH was measured and adjusted prior to experiment by adding NaOH to be within 6.5-8 range and turbidity was less than 5 NTU for better results of disinfection (WHO, 2011). Ammonia nitrogen was measured along the experiment as well as the temperature was 25 ^{o}C at laboratory during the test.

3.7.4 Total Chlorine Residuals Measurement

Total chlorine residuals were measured by using DPD (4500 Cl G) colorimetric method that is approved by APHA and AWWA. Total chlorine residuals were measured for the six doses (1.5, 2.5, 3.5, 4, 4.5, 5) mg/L and for the specific contact time (0.5, 2, 4, 8, 24 hours) respectively. Total chlorine residuals are equal to FAC plus combined chlorine residuals after satisfying water demand so the following equation (3.2) explains total chlorine residuals:

$$\text{Total Chlorine (TC)} = \text{Free Chlorine (FC)} + \text{Combined chlorine (CC)} \qquad 3.2$$

3.7.5 Chlorine Demand

As a chlorine is a strong oxidant it will combine with many substances including iron, manganese, ammonia and other inorganic and organic material in water. Aqueous solutions with pH 7.0 to 8.5, HOCl reacts rapidly with ammonia to form inorganic chloramines (combined chlorine term) in a series of competing reactions (USEPA, 2006). These reactions are instantenoiuse with no appreciable disinfection occurring until this initial “chlorine demand” is met. The following equation (3.3) and Figure 3.6 chart shows the chlorine demand:

$$\text{Chlorine demand (mg/L)} = \text{Total chlorine (mg/L)} - \text{Chlorine residuals (mg/L)} \tag{3.3}$$

Chlorine demand was measured for each chlorine dose after adding sodium hypochlorite standard solution for each sample and measuring total chlorine for all dosages. Chlorine demand value is less than total chlorine residuals and that indicates that the amount of sodium hypochlorite that added to water samples was sufficient with designed targeted dosage to meet the disinfection requirements.

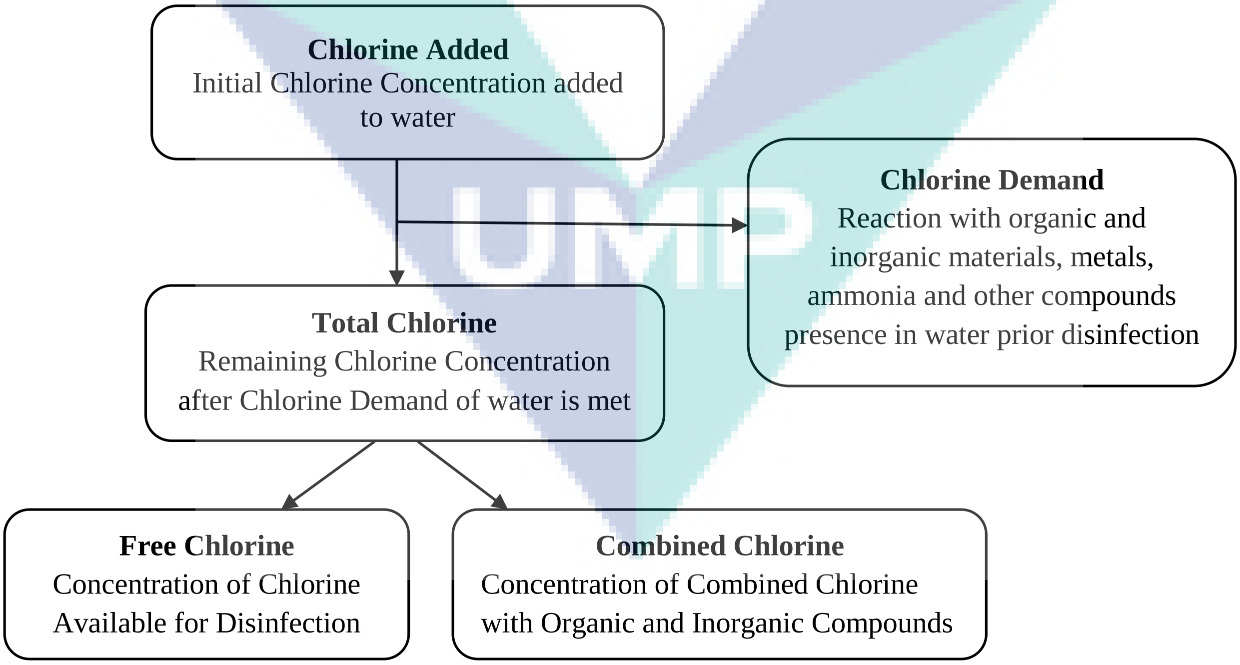

Figure 3.6 Flowchart of chlorine demand in water

3.8 Control Parameters of Chlorination Disinfection Process

Generally, the factors that affect the disinfection process are ammonia nitrogen, pH, temperature and contact time. The following sections explain briefly about these parameters.

3.8.1 pH of the Water

The disinfectant efficiency of hypochlorous HOCl is much higher than that of hypochlorite ion OCl^- (AWWA, 2018). When pH increases, the contact time requirement for destruction the pathogens increase too. pH for rainwater samples measured before chlorination process and neutralized for samples of pH less than 6.5 by adding sodium hydroxide (NaOH). pH was measured for each rainwater sample after dosing sodium hypochlorite solution. The following equation (3.4) shows the reaction of chlorine with water and the formation of HOCl.

$$NaOCl + H_2O \rightarrow HOCl + NaOH \qquad 3.4$$

3.8.2 Water Temperature

Water temperature for drinking water affects the rate of disinfection, with the colder water the inactivation rates of chlorine disinfection increase (USEPA, 2006). The temperature of rainwater samples was measured before and during dosing process and the samples temperature was 24.5 ^{o}C inside the laboratory.

3.8.3 Chlorine Concentration and Contact Time

The effectiveness of chlorination process depends on two main factors, concentration [C] and contact time [T]. The destruction of pathogens and organisms, often referred to as the kill viruses and it is directly related to these two factors (Hau & Reckhow, 2012). The following equation (3.5) shows the effectiveness of chlorine:

$$\text{Chlorine Effectiveness} = C \times T \tag{3.5}$$

3.8.4 Ammonia Effectiveness on Chlorination Process

The chlorination process can be affected by the ammonia nitrogen presence in water and can increase the combined chlorine residuals (AWWA, 2018). Ammonia nitrogen was tested for rainwater samples before and after the dosing of sodium hypochlorite solution into rainwater samples. Equations (3.6), (3.7) and (3.8) demonstrates the reaction of ammonia with water during chlorination process.

$$HOCl + NH_3 \rightarrow NH_2Cl\ (monocloramine) + H_2O \tag{3.6}$$

$$HOCl + NH_2Cl \rightarrow NHCl_2(dicloramine) + H_2O \tag{3.7}$$

$$HOCl + NHCl_2 \rightarrow NCl_3(nitrogen\ trichloride) + H_2O \tag{3.8}$$

3.9 Statistical Analysis

The data were analysed by using Microsoft Excel 2010, XLSTAT, Minitab 17. All necessary data were driven into this software. one-way ANOVA was applied to analyse physicochemical and microbiological rainwater parameters during seasonal changes. Also a descriptive analysis was used to compare the measured variables with World Health Organization and Malaysian Drinking Water Standards. Mean, median, standard deviation, minimum, maximum, variance was calculated and described in table as shown in Appendix B. One-way ANOVA analyses by comparing mean values was applied to determine the physicochemical water quality parameters changes during (pre-monsoon, monsoon and post monsoon season) and comparing it to Malaysian Drinking Water Quality Standards (MDWQS) and World Health Organization water quality standards (WHO). Normality test was applied for water quality parameters. Analysis of Variance (One-way ANOVA) were applied to analyse the microbiological quality of harvested rainwater system and the variation of bacteria existence in rainwater harvesting system during seasonal changes (pre-monsoon, monsoon and post monsoon season) while correlation and regression analysis were applied to analyses chlorine residuals reaction and regression with contact time.

3. 10 Summary

The experimental design and analytical methods were discussed in this chapter. Sample collection, characterization, preparation methods also has been demonstrated. The detailed characteristics of physiochemical and microbiological rainwater harvesting system water quality parameters and type of tests have been explained and the chlorination dosages design experimental method set up was covered up in this chapter with the designed contact time, the effect of control parameters on chlorination process was also discussed through this chapter. All these discussions make a better understanding for the methodology research study

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Through this chapter the implementation focus to describe the experimental outcomes and the discussion of the measured physicochemical and microbiological parameters and the determination of the optimum chlorine (sodium hypochlorite) dose to eliminate the microbial contamination from the harvested rainwater of WASRA system. The physicochemical parameters that were considered and examined in this study were, pH, temperature, conductivity, salinity, Dissolved Oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), total alkalinity (TA), turbidity and the chemical parameters Zink (Zn), chloride (Cl), ammonia nitrogen (NH_3-N) and hardness as calcium and magnesium ($CaCO_3$). Microbiological parameters for both *E. coli* and total coliform were analysed through this study. Total chlorine residuals (TC) and free available chlorine residuals (FAC) were measured within specific contact time of (0.5, 1, 2, 4, 8, and 24 hours) with different dosages of (1.5, 2.5, 3.5, 4, 4.5 and 5 mg/L) to achieve the proposed acceptable free available chlorine dose of no more than 2 mg/L after 30 minutes' contact and more than 0.2 mg/L after 24 hours' contact time.

The objective of this study is to carry out the physicochemical and microbiological parameters of rainwater harvesting system in Gambang and comparing the results with Malaysian Drinking Water Quality Standards and World Health Organization. Also using the proper treatment to eliminate the microbiological contamination by using sodium hypochlorite solution of 15 % concentration with specific doses and contact time. Therefore, this chapter demonstrates all statistical analysis and calculations of physicochemical and microbiological parameters of rainwater harvesting system rainwater harvesting system and the calculations of FAC and TC residuals with contact time.

4.2 Statistical Analysis of Physicochemical Rainwater Parameters

Rainwater samples were collected from rainwater harvesting system, during pre-monsoon, monsoon and post monsoon season to analyse the physicochemical parameters of temperature (T), turbidity, conductivity (EC), Alkalinity (Al), total suspended solids (TSS), salinity, total dissolved solids (TDS), dissolved oxygen (DO), and chemical parameters, pH, hardness as magnesium and calcium ($CaCO_3$), chloride (Cl^-), Zink (Zn), and nitrogen ammonia (NH_3-N). All physicochemical rainwater parameters were below the maximum contamination levels of World Health Organization (WHO, 2011) and Malaysian Drinking Water Standards (MDWQS, 2004). Descriptive statistics and one-way ANOVA were applied to analyse the physicochemical parameters during seasonal change of (pre-monsoon, monsoon and post monsoon) and comparing the mean values for a significant change in *P* value that is less than 0.05. Minitab 17 was used for analysing the data for one-way ANOVA comparing by mean values (Minitab, 2014). All mean values were compared to World Health Organization and Malaysian Drinking Water Quality Standards. Normality test has been applied for water parameters by using commercial statistical program XL stat. Appendix B and C show normality and statistical results of physicochemical parameters.

4.2.1 Temperature

Temperature is a significant biological affecting factor, which plays an important role of the metabolic endeavour of microorganisms (Sirajudeen & Mubashir, 2013). All the measured temperature values of the rainwater harvesting system are presented in Figure 4.1. The temperature of the rainwater harvesting system was found to be stable on the daily basis during collecting samples. However, there were little change from day to day and during day time and sunlight it was little higher and especially during pre-monsoon season through August, September and first part of October and the minimum was 22 ^{o}C while the maximum was 33^{o}C. Throughout sunlight hours there was a stratification nearly 4-5 degrees. This stratification can be disrupted by rainfall and as it is known that Malaysia has a tropical climate and there is a slightly changes in temperature through the year and especially through rainy season or as known as a monsoon season where temperature can drop few degrees but the average temperature through the year 20-30 ^{o}C (NAHRIM, 2014). Figure 4.1 shows the temperature values of harvested rainwater samples. One Way ANOVA test was applied on harvested rainwater sample's temperature to check the variability in temperature through the seasonal change and the p value was <1.0 and there was a significant change in rainwater temperature by comparing means values.

Normality test and frequency distribution has been applied for testing the distribution of temperature data and by using Kolmogorov-Smirnov test with normal distribution histogram with sigma value equals to 2.079. The *P* value for pre-monsoon is 0.811 while *P* value for monsoon equals to 0.354 and post-monsoon is 0.03. As the data of both pre monsoon and monsoon season are distributed normally and >0.05 while the data of post-monsoon season is not normally distributed and *P* value is less than 0.05. Appendix B shows the distribution results of normality test and Appendix C shows the descriptive statistics of physicochemical parameters.

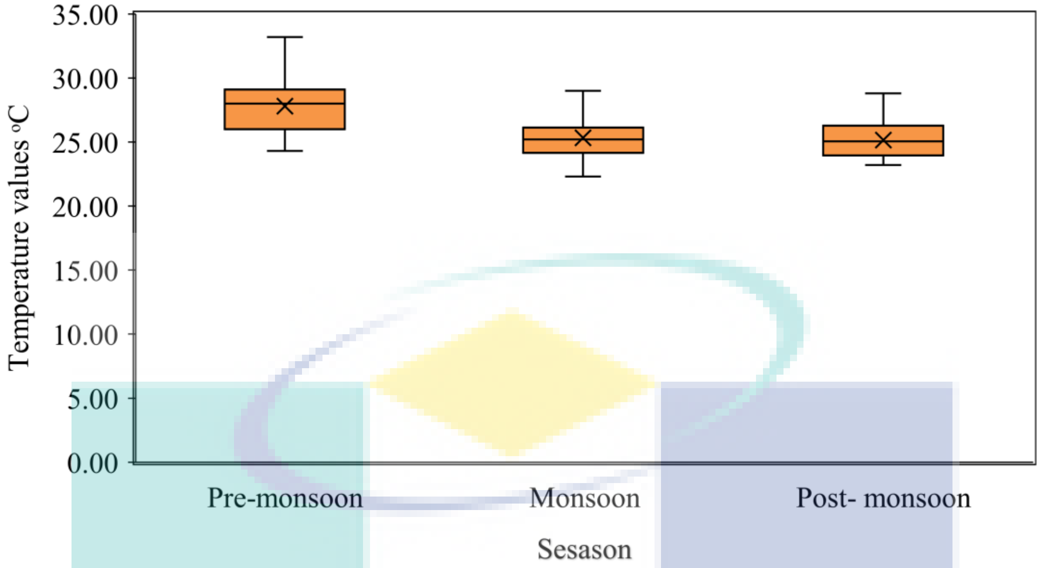

Figure 4.1 Temperature variation values (°C) of harvested rainwater samples

4.2.2 pH

pH is a measure of a solution's acidity and it is measured by logarithmic scale from 1-14 and the range of normal pH in surface water lies between 6.5-8.5, so generally water with less than 6.5 considered to be acidic (WHO, 2011). Low pH values have no health effects but pH lower than 7 is acidic and tends to be corrosive and acidic rainwater can leach metals from plumbing system which can cause pipe to leak.

The pH values of harvested rainwater fluctuated during the sampling period and the mean value of post monsoon was 5.75 which was the lower one while a monsoon season mean value was 6.57 and 6.31 for post-monsoon season as shown in Appendix C. Both pre-monsoon and post monsoon have lower values than the WHO and MDWQS water quality standards and only during monsoon season the pH value was within limits. The *P* value is less than 0.05 and there is a significant difference in mean values comparison of one ANOVA test for the pH seasonal change. Normality distribution by using Kolmogorov-Smirnov test has been applied to check the data normality distribution for the pH.

The *P* value of normality test of pH for pre-monsoon season equals to 0.624 and for monsoon is 0.449 while for post monsoon equals to 0.136 and all are larger than 0.05 and the data distribution is normal for the three seasonal monsoon changes. Appendix B shows the results of normality test.

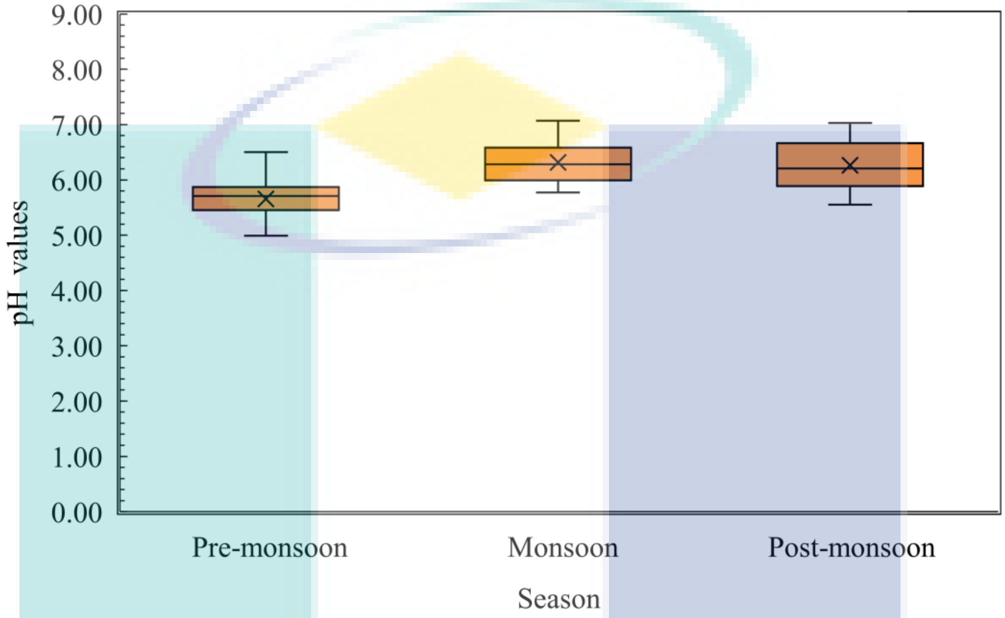

Figure 4. 2 The pH values of harvested rainwater samples during seasonal changes

4.2.3 Total Alkalinity

Alkalinity is the measurement of a water's ability to neutralize acids. It usually indicates the presence of carbonate, bicarbonates, or hydroxides. Alkalinity results are typically expressed as mg/L $CaCO_3$. Alternatively, they are sometimes reported as mg/L HCO3 and the following relationship applies:

Alkalinity (mg/L as HCO_3) = Alkalinity (mg/L as $CaCO_3$) X 1.22 (4.1)

In natural waters, there is a close relationship between alkalinity and hardness as waters with high levels of alkalinity has a higher level of hardness and the water cannot be acceptable to drink due to high level of $CaCO_3$. Water with low alkalinity has little capacity to buffer acidic inputs and is susceptible to acidification (low pH). There are no applicable standards of WHO and MDWQS regarding alkalinity. There are no health issues related to alkalinity but it affects aquatic life especially sensitive species and animals (Kumar & Puri, 2012). There were changes of water alkalinity during monsoon seasonal changes as the lowest was on pre-monsoon and equals to 10.77 mg/L while during monsoon the alkalinity rise up to 12.12 mg/L and went down during post-monsoon to 11.25 mg/L. There was a significant change among means values of alkalinity during seasonal changes and *P* value is less than 0.05 by comparing the mean values using one-way ANOVA test.

Normal distribution has been applied for total alkalinity by using histogram distribution and Kolmogorov-Smirnov test. The *P* value equals to 0.127 for pre-monsoon, 0.065 for post monsoon season and both values are > 0.05 which means alkalinity has a normal distribution data while *P* values equals to 0.041 for post-monsoon season which refers that data is not distributed normally as it is less than 0.05. Figure 4.3 shows the values of alkalinity of harvested rainwater samples versus the seasonal changes. Appendix B shows more details of normality test and Appendix C shows descriptive statistics results of physicochemical parameters.

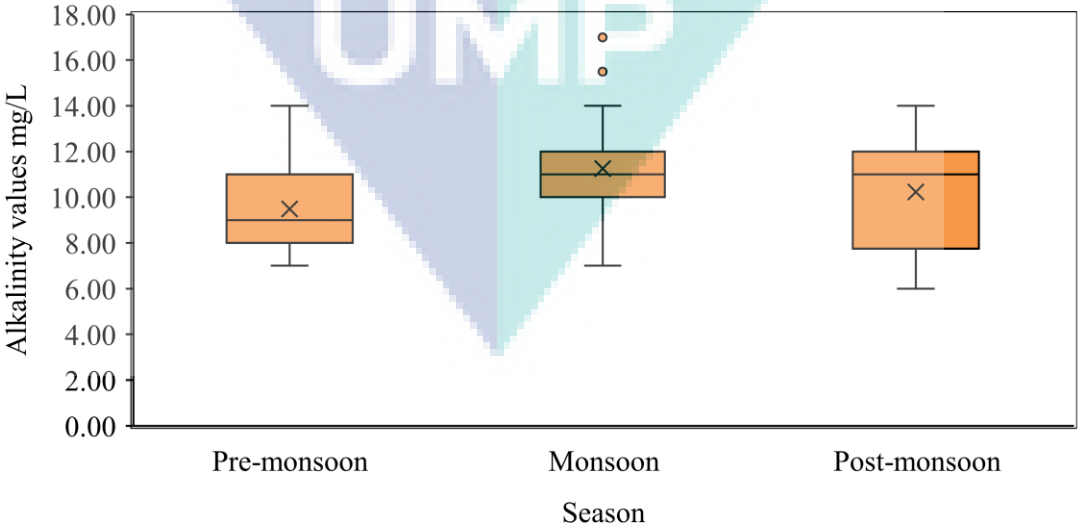

Figure 4.3 Total Alkalinity ($CaCO_3$) values in harvested rainwater samples

4.2.4 Turbidity

There is no health guideline for turbidity but the recommended value is always below 5.0 NTU for the best and most effective water disinfection purposes (WHO, 2011). The turbidity of harvested rainwater was below the maximum value that is recommended by WHO and MDWQS and as shown in table in Appendix C. The *P* value was less than (0.001) and below (0.05) and it was significantly different during seasonal changes. The turbidity of the harvested rainwater system was changing and it was obvious that it was low through pre-monsoon season little higher through monsoon and rainy season. Figure 4.4 shows the turbidity variation values of harvested rainwater samples through sampling time period.

Normality test by using Kolmogorov-Smirnov statistical test has been applied for turbidity distribution, *P* value equals to 0.176 for post monsoon, 0.027 and 0.066 for monsoon and post-monsoon respectively and as *P* value larger than 0.05 for both pre monsoon and post monsoon which means the data for both seasons are distributed normally but not for the monsoon season as it is less than 0.05. Figure 4.4 demonstrates the turbidity values of the rainwater harvested samples versus seasonal changes. Appendix B shows more details of normality distribution test and Appendix C shows descriptive statistical analyses results.

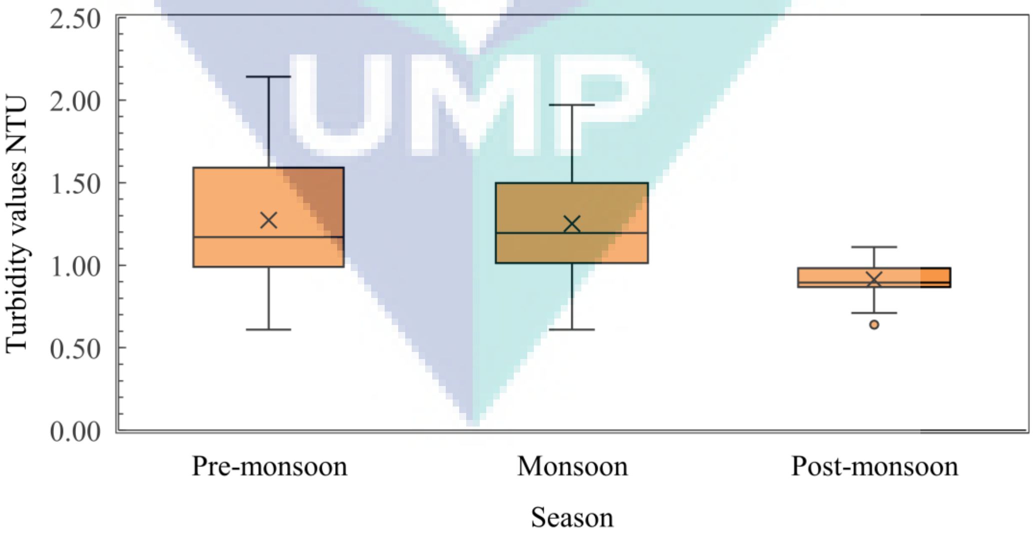

Figure 4.4 Turbidity values (NTU) in harvested rainwater samples

4.2.5 Electrical Conductivity

The electrical conductivity (EC) is an indicator measure of the salt in the water. From Figure 4.5 it is observed slightly changes in conductivity values and little higher in a pre-monsoon season despite that all samples were below the drinking water quality guidelines and the *P* value was significantly different during seasonal changes and below (0.05) by comparing mean values of EC as the highest value was during a pre-monsoon season and equals to 64.23 µS/cm while during monsoon equals to 49.22 µS/cm and the lowest during post-monsoon 45.73 µS/cm.

The following Figure 4.5 shows the variation in rainwater harvesting system conductivity values throughout sampling time period. Normal distribution test has been applied to electrical conductivity data, the *P* value equals to 0.545 for a pre-monsoon, 0.096 for monsoon and 0.354for the post-monsoon season and all *P* values are larger than 0.05 which means all data are distributed normally through seasonal changes and following Kolmogorov-Smirnov normality test. Appendix B shows more details of normality distribution test details and descriptive statistical results.

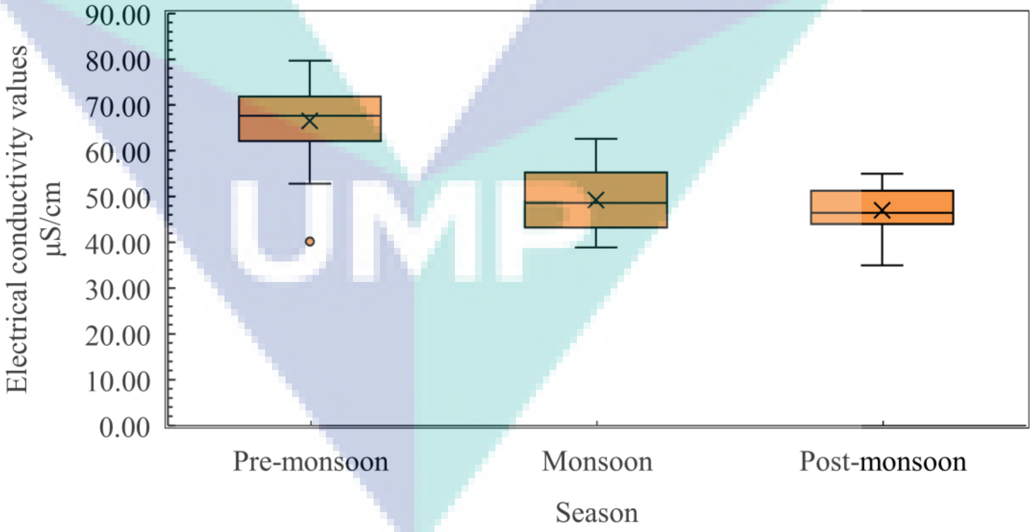

Figure 4.5 Electrical conductivity values (µS/cm) in harvested rainwater samples

4.2.6 Salinity

Salinity is the amount of dissolved salts in water but usually rainwater known to be a fresh water however, it can get the salt compounds through the dissolved particles in the atmosphere and from catchment area of rainwater harvesting system (Dauod et. al. 2011). During rainwater sampling process, salinity remained stable and equal to zero (o/00) for all collected samples, the *P* value was equal to 0 and there is no significant change in mean values for seasonal change.

Figure 4.6 shows the salinity values of harvested rainwater samples versus seasonal changes. Normal test distribution was applied to salinity data and the *P* value is less than 0.001. The data distribution of salinity is not following normality distribution for the pre-monsoon, monsoon and post monsoon season and it is not normally distributed. Appendix B gives more details about normality distribution test details and descriptive statistical results.

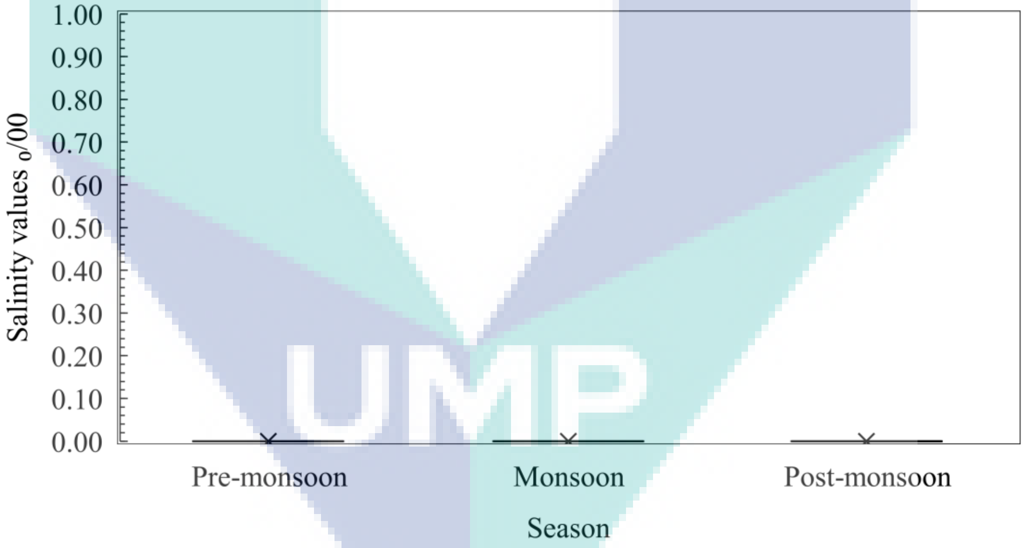

Figure 4.6 The values of salinity in harvested rainwater samples

4.2.7 Total Dissolved Solids

Total dissolved solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter that present in water and usually are calcium, magnesium. Sodium and potassium cations and carbonate and the presence of TDS may affect the taste of drinking water if it is above the allowable limits and the water with TDS value less than 300 mg/L considers an excellent but very low TDS may be unacceptable because of it is plane inside test (WHO, 2011).

The summary of TDS concentration and mean values were below the WHO and MDWQS guidelines and presented in Appendix C. The *P* value was less than 0.001 of comparing mean values for monsoon seasonal change and is less than 0.05 and there is a significant difference among mean values of (pre-monsoon, monsoon and post monsoon) seasons. The following Figure 4.7 shows the variation of TDS of harvested rainwater samples. Normality test was applied by using Kolmogorov-Smirnov test as *P* value for pre-monsoon equals to 0.156 and for monsoon is 0.027 and for the pre-monsoon season is 0.345. As the *P* values for both seasons of pre-monsoon and post monsoon >0.05 which shows that data are distributed normally and larger than alpha value 0.05 and that indicates that TDS values are normally distributed. The *P* value for monsoon is less than 0.05 which indicates that data are not distributed normally. Appendix B shows the values of normality distribution test and Appendix C shows the descriptive statistics of physicochemical parameters.

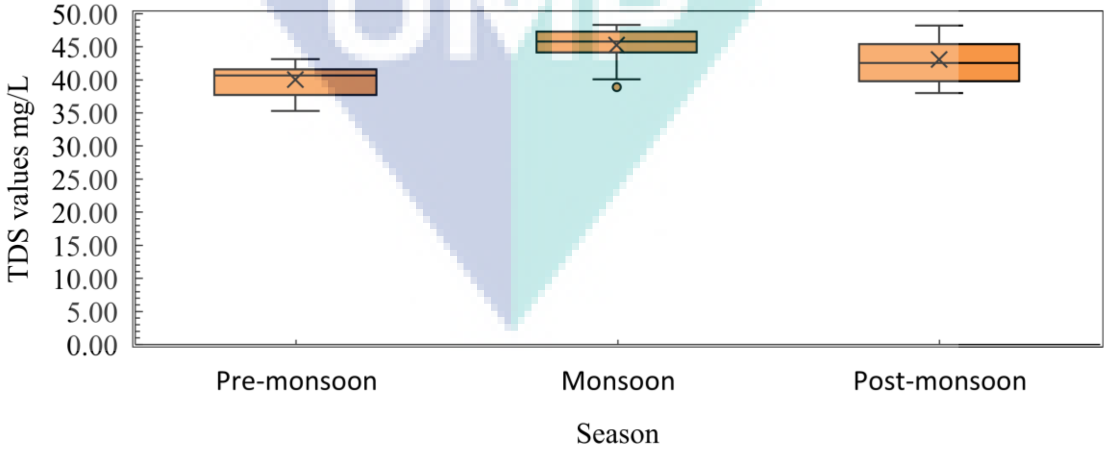

Figure 4.7 The values of TDS (mg/L) in harvested rainwater samples

4.2.8 Total Suspended Solids

Total suspended solids include all the particles that suspended in water which will not pass through a filter. Total Suspended solids can absorb heat from sunlight which increase the temperature of water and that will affect the levels of a dissolved oxygen in water. A warm water can help to increase the growth of organisms and also can affect the disinfection of water process (Qasim, 2017). Most of people tend to consider that a concertation of TSS of the water less than 20mg/L is very clear (Frankenberger & Esman, 2012). The results of TSS of harvested rainwater samples were below the WHO and MDWQ standards for all three seasons of monsoon and *P* value was less than 0.001 and it is less than 0.05 which shows a significant difference during seasonal changes and descriptive detailed results can be found in Appendix C. Figure 4.8 shows the variation values of TSS in harvested rainwater samples. Kolmogorov-Smirnov normality test distribution was applied and the data of TSS were distributed normally.

The *P* value for both pre-monsoon and monsoon season equals to 0.15 and 0.28 respectively and it is larger than 0.05 while *P* value for post monsoon equals to 0 and less than alpha 0.05 which indicates that data is not distributed normally during post-monsoon season. Appendix B includes more details of normality distribution detailed results.

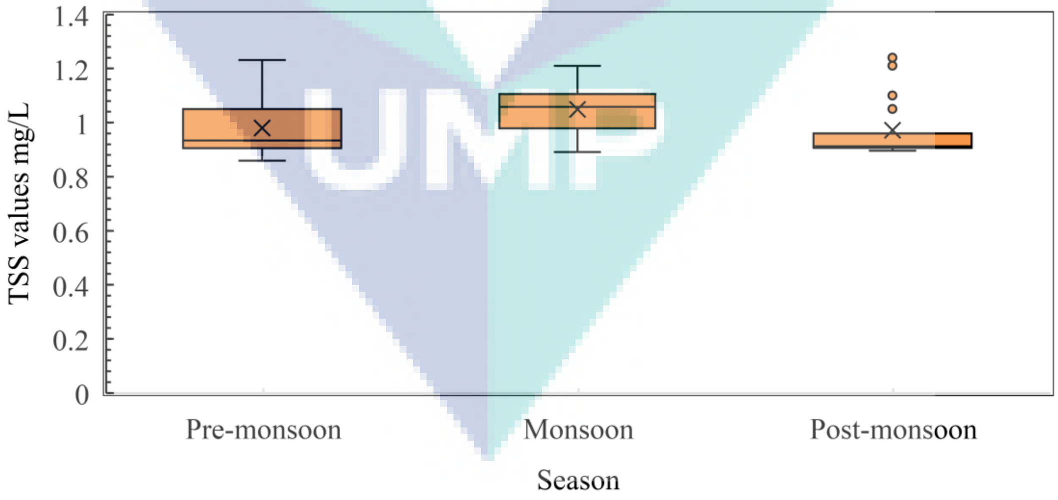

Figure 4.8 The values of TSS (mg /L) in harvested rainwater samples

4.2.9 Dissolved Oxygen

Dissolved oxygen (DO), is the amount of oxygen gas that dissolved in water and available for use by plants and aquatic species (WHO, 2011), and it can vary in daily and seasonal patterns and decrease with high temperature and salinity and the maximum solubility of oxygen in water ranges from 15 mg/L at 0 °C to 8 mg/L at 30 °C thus DO levels indicate high biological demand which is linked to polluted waters (Moon et. al. 2009). The *P* value was less than 0.001 and there is a significant difference between mean values of DO results during seasonal changes and as shown in Appendix C. The following Figure 4.9 shows the values of dissolved oxygen in harvested rainwater samples versus seasonal changes.

Distribution of normality test has been applied to all DO values and it appears that DO data of pre-monsoon and monsoon seasons are distributed normally by using histogram and Kolmogorov-Smirnov test as *P* value equals to 0.349 and 0.145 respectively while for post-monsoon season equals to 0.014 which is less than 0.05 alpha value and the data was not distributed normally during post-monsoon season. Appendix B gives more details of normality distribution test.

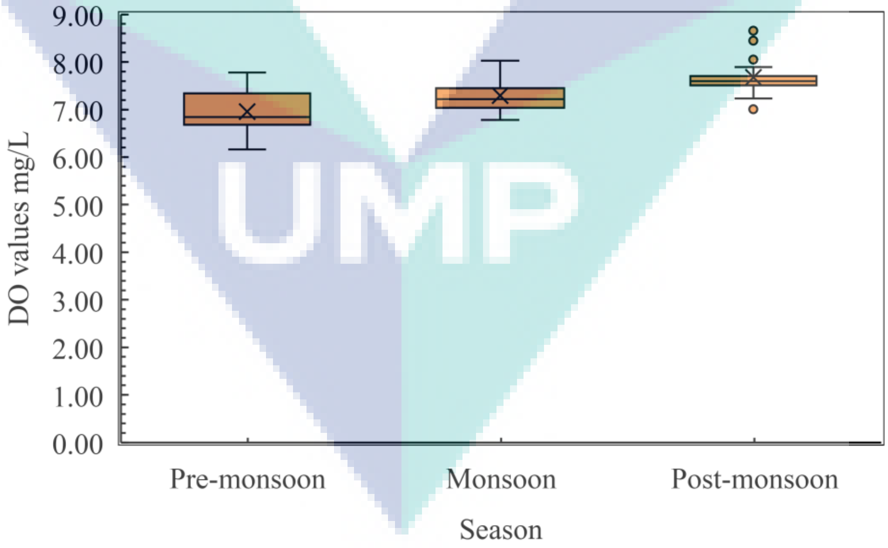

Figure 4.9 Dissolved Oxygen values (DO) mg/L in harvested rainwater

4.2.10 Chloride

Chloride in drinking water generates from natural sources from surrounding environment, atmosphere, sewage and industrial effluents, urban runoff containing de-icing salt and saline intrusion (Adhikary et al. 2012). A human can expose to chloride by a main source which is the addition of salt to food and there are no health-based guidelines is proposed for chloride in drinking water. Yet too much chloride concertation in drinking water may give test in drinking water and can cause corrosion for water pipes (WHO, 2011). The results of chloride of rainwater samples were so small and below the WHO and MDWQ Standards and the mean values of all seasons were very low comparing to the values of water guidelines standards of WHO and MDWQ Standards respectively as the source of this chloride is from atmosphere and the surrounding environment and Appendix C gives more descriptive statistical details. The *P* value is less than 0.001 and there is a significant difference in mean values between the monsoon seasonal changes. Figure 4.10 shows the results of chloride of harvested rainwater samples. The data of chloride for the pre-monsoon, monsoon and post monsoon season were distributed normally and the *P* values were equals to 0.897, 0.133 and 0.679 respectively and all *P* values > 0.05. Appendix B shows detail results of normality distribution test.

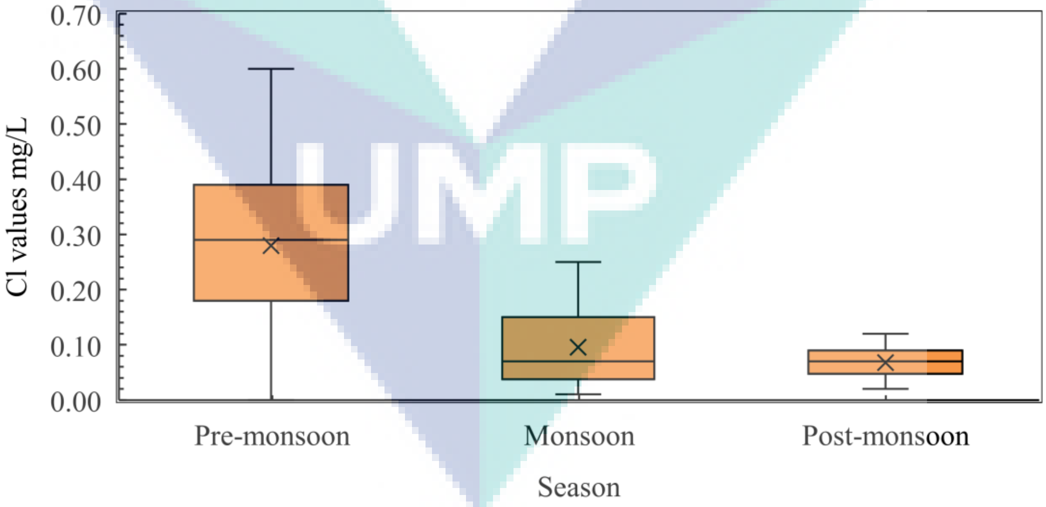

Figure 4.10 Chloride values (mg/L) in harvested rainwater samples

4.2.11 Zinc

Zinc is an essential element found in virtually all food and potable water in the form of salts or organic complexes and zinc considered to be unacceptable in drinking water for consumers if exceeded 3 mg/L (WHO, 2011). Figure 4.11 shows zinc values of rainwater harvested samples and all values were below the WHO and MDWQS water quality guidelines standards as shown in Appendix C.

The *P* value was less than 0.05 which shows a significant difference among mean values of monsoon seasonal changes. Zink data were not distributed normally for pre-monsoon season as *P* value is 0.04 and less than 0.05 while P values for monsoon and post-monsoon equal to 0.0186 and 0.904 respectively and more than 0.05 and the data were distributed normally and following Kolmogorov-Smirnov test. Appendix B shows detailed results of normal distribution test and descriptive analyses results.

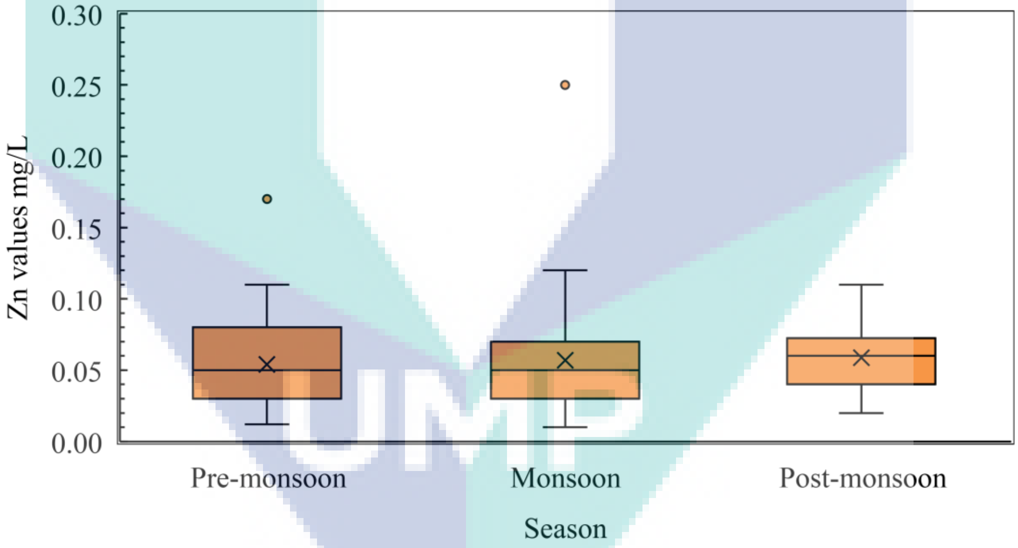

Figure 4.11 The values of zinc in harvested rainwater samples (mg/L)

4.2.12 Ammonia Nitrogen

Ammonia is a nutrient that contains nitrogen and hydrogen. Its chemical formula is NH_3 in the un-ionized state (Pan et al. 2012). It is naturally found in surface and rainwater and the maximum acceptable level is 1.5 mg/L (WHO, 2011). Nitrogen ammonia (NH_3-N) levels were below the WHO and MDWQ Standards during this study mean values of all monsoon seasonal changes were below 1.5mg/L.

The *P* value was below 0.05 which shows a significant different of monsoon seasonal changes by comparing mean values using one-way ANOVA test. As the maximum mean value during pre-monsoon season and the lowest was during monsoon season. Low nitrogen ammonia also refers to low chemical contamination in rainwater samples. Figure 4.12 shows the values of nitrogen ammonia (NH_3-N) during monsoon seasonal changes. Nitrogen ammonia data were following a normal distribution as *P* values for pre-monsoon, monsoon and post monsoon were equal to 0.127, 0197 and 0,115 respectively and all *P* values > 0.05. Appendix B shows more detailed results of normality distribution test and descriptive analyses results.

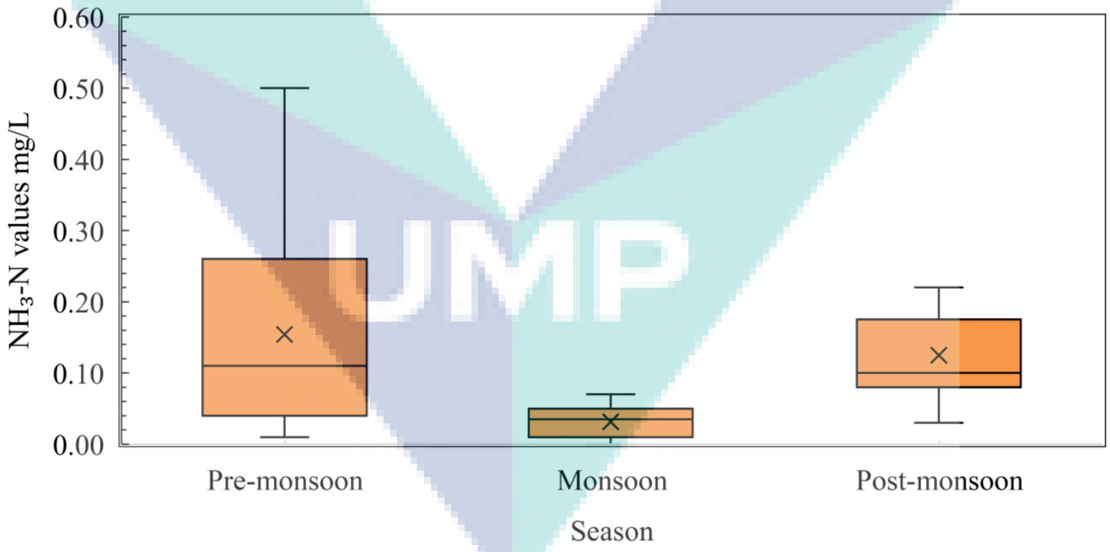

Figure 4.12 The values of Ammonia Nitrogen (mg/L) in harvested rainwater samples

4.2.13 Hardness as Calcium

Calcium salts and calcium ions or calcium carbonate are among the most commonly occurring in nature and they may result from the leaching of soil and other natural sources or may come from man-made sources such as sewage and some industrial wastes (Förstner & Wittmann, 2012).

Calcium is usually one of the most important contributors to hardness and calcium concentration in natural waters are typically less than 15mg/l (WHO, 2011). Calcium as $CaCO_3$ values were below WHO and MDWQS and *P* value is equal to 0.02 shows a significant difference in mean values of monsoon seasonal changes. Figure 4.13 shows the values of calcium as hardness of harvested rainwater samples. Hardness data of calcium $CaCO_3$ were analysed for normality test and the results a pre-monsoon data were not following the normal distribution as *P* equals to 0.02 and it is less than alpha 0.05, while *P* values for monsoon and post monsoon were equals to 0.906 and 0.108 respectively and distributed normally. Appendix B shows the results of normality distribution test and descriptive analyses results.

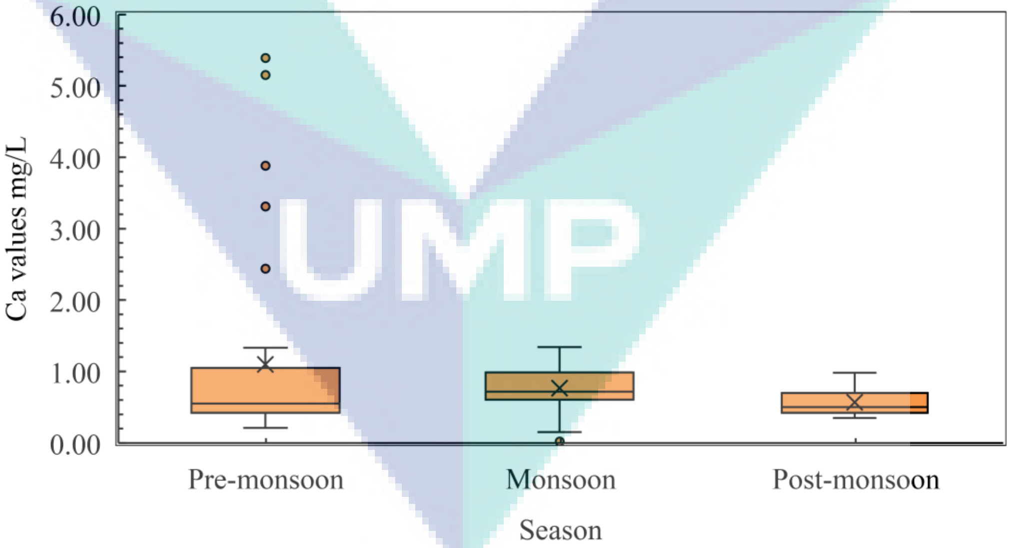

Figure 4.13 The values of hardness as calcium in harvested rainwater samples (mg/L)

4.2.14 Hardness as Magnesium

Magnesium is a common mineral which also contains calcium. Generally, Rainwater is soft because it contains few ions (Balomenos et al. 2014). Hardness as magnesium ($CaCO_3$) values of rainwater samples were below the WHO and MDWQS standards values as the mean values were very low and the *P* value is less than 0.05 which shows a significantly different in mean values for monsoon seasonal changes and were far below the values of WHO and MDWQS and as shown in Appendix C. Figure 4.14 shows the values of hardness as magnesium ($CaCO_3$) during seasonal changes. Hardness data as magnesium for post-monsoon season were not distributed normally and not following Kolmogorov-Smirnov test as *P* value equals to 0.07 and less than alpha 0.05, while for monsoon was equal to 0.641and for post monsoon was 0.023 and less than 0.05 and was not distributed normally. Appendix B shows the results of normal distribution test.

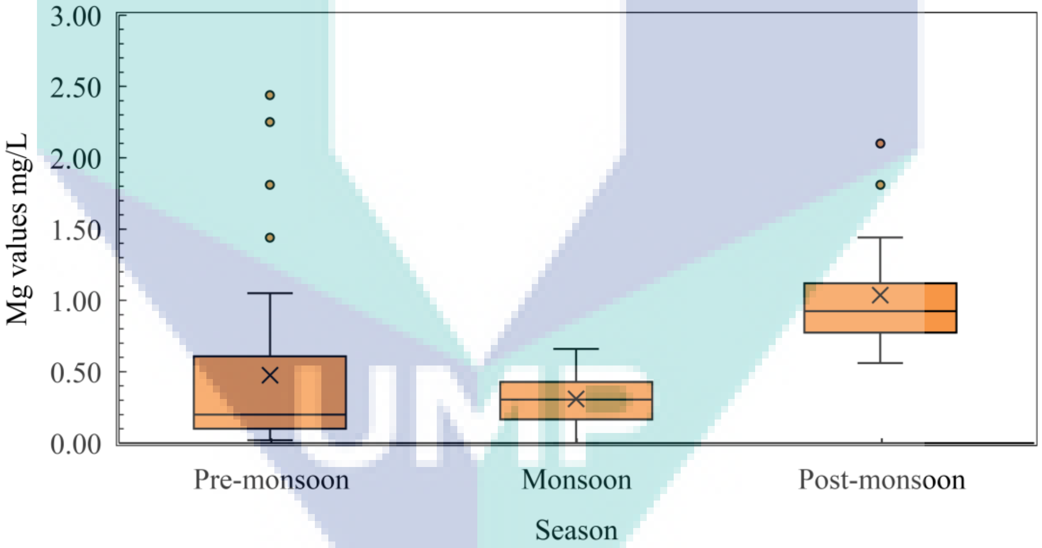

Figure 4.14 The values of Hardness as magnesium ($CaCO_3$) in harvested rainwater samples (mg/L)

4.3 Analysis of Microbiological Quality of Harvested Rainwater

A total of 40 samples were tested during the sampling period of time for the two widely known bacteria indicators of *Escherichia* coli (*E. coli*), and total coliform by using the Colilert-Technology IDEXX- Quaniti- tray- Quanti Try 2000 technique (APHA, 2005). All samples were analysed on the same day collected at the University environmental laboratory. The samples were collected during pre-monsoon season, monsoon and post monsoon season and there was a variability in bacteria contamination through sampling and testing time period.

4.3.1 Statistical Analysis of Microbiological Parameters of Harvested Rainwater Sample

The microbiological parameters of harvested rainwater were analysed by using descriptive statistical analysis to determine (minimum, maximum, standard deviation, mean and median) and comparing the mean values results with MDWQS and WHO guidelines. Analysis of variance (ANOVA) was applied to compare the mean results of both bacteria *E. coli* and total coliform during the seasonal variation (pre-monsoon, monsoon and post monsoon season) with MDWQS and WHO drinking water guidelines. Table 4.1 shows the details of descriptive analysis of microbiological parameters of the rainwater samples.

Table 4.1 Descriptive statistics data of microbiological parameters of rainwater samples

Variables	Units	Observation	Min.	Max.	Mean	Median	St.dev	WHO	MDWQS
Total coliform	MPN/100 ml								
Pre-monsoon		40	301.5	616.4	456.8	445.1	83.5	0	0
Monsoon		40	188.2	301.2	249.87	244.58	24.2	0	0
Post-monsoon		40	35.8	151	81.7	79.6	27.42	0	0
E. coli	MPN/100ml								
Pre-monsoon		40	10.5	16.3	12.807	12.650	1.503	0	0
Monsoon		40	7.2	10.9	9.030	9.250	0.960	0	0
Post-monsoon		40	0	7.4	5.012	5.100	1.479	0	0

4.3.2 *E. coli* Results

The total *E. coli* counts obtained by using Colilert IDEXX- Quaniti- tray- Quanti Try 2000 technique in MPN/100mL. From the statistical results from table 4.1 it shows that the mean values of *E. coli* were above the drinking water guidelines standards by WHO and MDWQS and it was fluctuated during the sampling time interval of pre-monsoon season which is the highest value that equals to 12.807 MPN/100Ml. Then getting lower by monsoon season and heavy rain season to 9.030 MPN/100mL to reach the lowest value during the post-monsoon season which equals to 5.012 MPN/100mL.

The minimum value was 0 MPN/100mL while the maximum value was 16.3 MPN/100mL, the *P* value is less than 0.001 comparing by the means of ANOVA analysis which shows a significant difference between the season variation of *E. coli* presence in harvested rainwater samples. A total of 34 rainwater samples were positive through testing time period and exceeding the recommended drinking guidelines standards of 0 MPN/100mL.

Figure 4.15 shows the presence, variation and concertation of *E. coli* in rainwater samples during the sampling period of time while. Appendix D shows the normality results of *E. coli* and one-way ANOVA analyses results comparing by means values and Appendix E shows Colilerts Quanti tray 2000 tables.

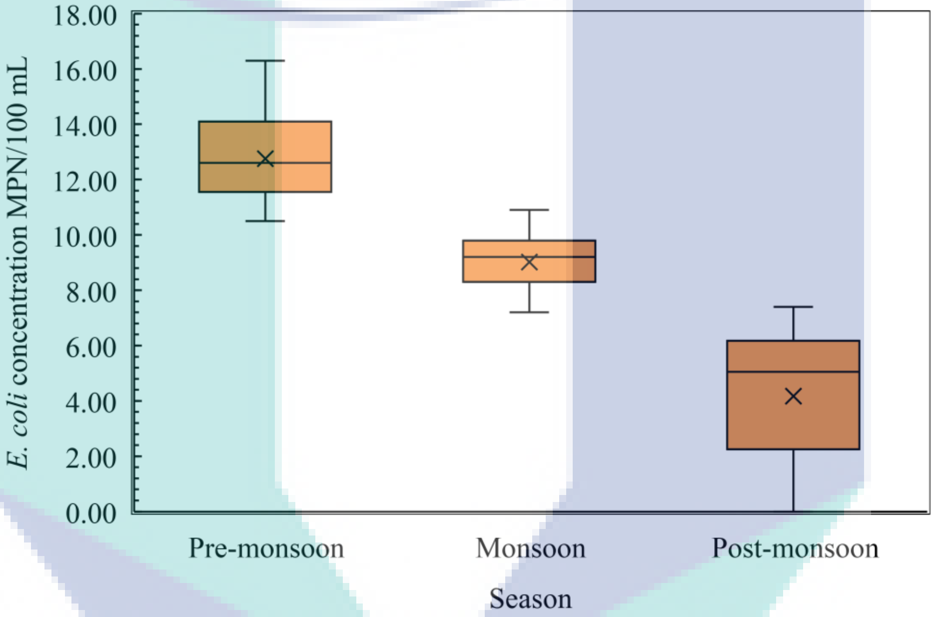

Figure 4.15 The presence and concentration of *E. coli* in rainwater sampl

4.3.3 Total Coliform Results

Total coliform counts obtained in this study by using Colilert Quanti-tray 2000 technology, MPN/100mL. All rainwater samples were positive from Table 4.1 the mean values of total coliform through sampling time period and seasonal changes were, 456.8 MPN/100mL during pre-monsoon, 249.87 during monsoon and 81.7 during post-monsoon, comparing these means values with drinking water guidelines standards, WHO and MDWQS respectively shows that the results exceeding the limits which is equal to 0 MPN/100mL while there was a variation in values through seasonal changes as shown in table 4.1. The *P* value is less than 0.001 which shows a significant difference in means values during seasonal interval time changes (pre-monsoon, monsoon and post monsoon season). Figure 4.16 shows the presence, concertation and variation of total coliform in rainwater samples. Appendix D shows normality distribution results for total coliform and one-way ANOVA analyses results comparing by means and Appendix E shows the tables of Quanti tray 2000 MPN/100 mL

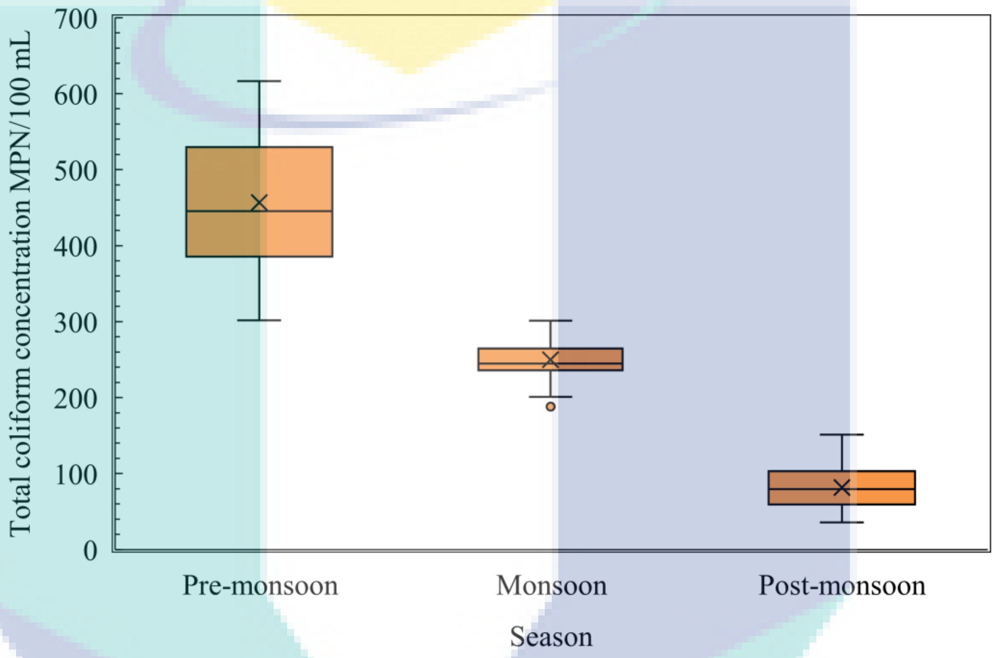

Figure 4.16 The presence and concentration of total coliform in rainwater samples

4.4 Rainwater Harvesting System Treatment

Chlorination was first used for disinfection for drinking water supplies in the early of 1990s as it is very effective and a very powerful disinfectant that contributed to reduce the water borne diseases dramatically besides it is available and affordable to use at point of use for drinking water by consumers (Whittington et al. 2012). Chlorination is the most common and appropriate method used to treat rainwater tanks, and to achieve an effective disinfection it is important to add a sufficient chlorine dose to provide a free chlorine residual of at least of 0.5 mg/L and not exceeding 5 mg/L and this definition is only appropriate when users drink water directly from the flowing tap (WHO, 2011). While USEPA recommended a dose between 4.44 mg/L-7.41 mg/L for drinking water for a household purposes (USEPA, 2006). However, this residual can be achieved under ideal disinfection conditions of ambient temperature, pH equals to 7 and turbidity less than 1 NTU.

There is no definite standards or guidelines for chlorine dosage for rainwater harvesting system treatment but the Centre for Diseases Control and Prevention (CDC) proposed a dose of 2 mg/L as maximum for free available chlorine residuals (FAC) after 30 minutes' contact time to certify that water does not have unpleasant taste and odder and a minimum dose of 0.2 mg/L after 24 hours contact time to confirm that water is safe to consume (CDC, 2014). The following section presents the results of free available chlorine residuals (FAC), total chlorine residuals (TC), chlorine demand and the effectiveness of sodium hypochlorite solution.

4.4.1 Free Available Chlorine (FAC) Residuals Versus Contact Time

Sodium hypochlorite solution of (15%) concentration was added to rainwater samples with different doses and with specific contact time to determine the proper dose that should be not more than 2 mg/L as free available chlorine residuals after 30 minutes' contact time and not less than 0.2 mg/L after 24 hours contact time.

Sodium hypochlorite was added in different doses to 1 litter of rainwater sample with a specific contact time the following table 4.2 shows the chlorine doses versus contact time.

Table 4.2 The chlorines doses versus contact time

Chlorine dose (mg/L)	1.5	2.5	3.5	4	4.5	5
Contact time (hours)	0.5, 1, 2,4, 8, 24	0.5, 1, 2, 4, 8, 24	0.5, 1, 2, 4, 8, 24	0.5, 1, 2, 4, 8, 24	0.5, 1, 2, 4, 8, 24	0.5, 1, 2, 4, 8, 24

pH of samples that were lower than 6.5 adjusted by adding drops of sodium hydroxide NaOH to rainwater samples to reach 6.5-7 for better disinfection results. Average temperature was 25.5 ^{o}C at laboratory and turbidity values range (0.92-1.01

NTU) and NH_3-N range (0.019 - 0.009 mg/L). Samples of rainwater were dosed with 1.5 mg/L Sodium hypochlorite solution within contact time interval (0.5-24) hours with pH value 6.80 and average temperature 25.5 °C and turbidity average 0.91 NTU, NH_3-N average 0.071 mg/L and the volume of rainwater samples was 1 liter. The *P* value equals to 0.003 and less than 0.05 and R^2 value equals to 95.6 and $r = -0.92$ which shows a very strong correlation and relation between contact time and FAC residuals as chlorine residuals decay within contact time period. The free available chlorine residuals concentration (FAC) equals to 0.71 mg/L after 30 minutes' contact time and less than 2 mg/L while (FAC) equals to 0.05 mg/L and less than 0.2 mg/L after 24 hours contact time and that indicates the dose of 1.5 mg/L is not sufficient to meet the requirements of water disinfection. The *P* value equals to 0.003 and it is significantly less than 0.05. Figure 4.17 shows the concentration of (FAC) residuals of 1.5 mg/L dosage versus contact time. Appendix F shows the results of regression and correlation test of (FAC) residuals versus contact time.

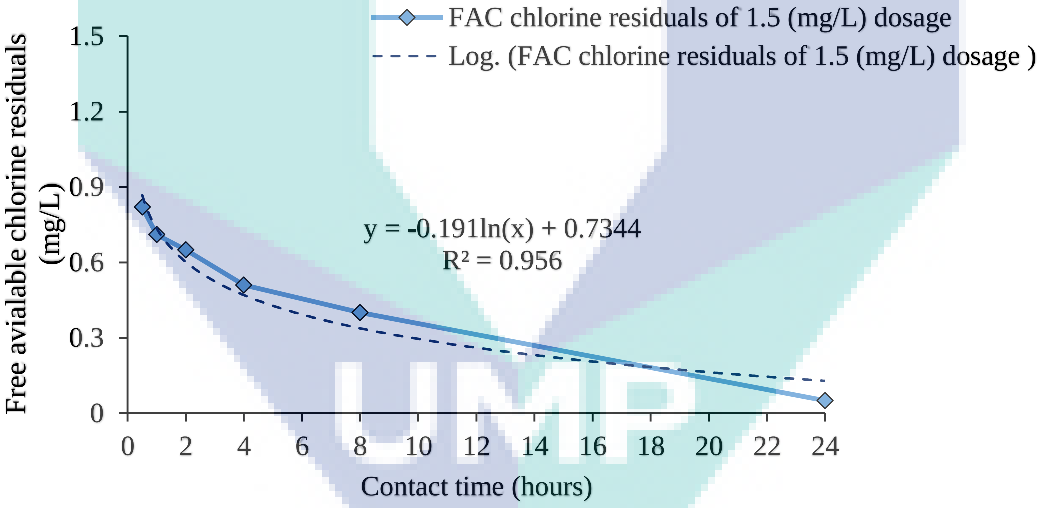

Figure 4.17 The concentration of FAC residuals of 1.5 mg/L versus contact time

A dosage of 2.5 mg/L sodium hypochlorite were added to 1 litter of each of rainwater harvested samples within contact time period minimum 0.5 hour and maximum 24 hours. The pH value was equal to 7.09, average temperature 25.5 °C and average turbidity recorded 0.92 NTU with average NH_3-N equals to 0.086 mg/L. The *P* value equals to 0.007 for regression test which is significantly below 0.05, R^2 equals to 82.91% and r = - 0.93 which shows the correlation between FAC residuals decay and contact time. The FAC residuals after 30 minutes' reaction were equal to 0.9 mg/L which is less than 2mg/L while the FAC residuals after 24 hour reaction time were 0.09 mg/L which is lower the requirement of 0.2mg/L thus this dosage is not meeting the disinfection requirements and the FAC residuals decline below the 0.2 mg/L within 24 hours' period of contact time. Figure 4.18 shows the concentration of FAC residuals versus contact time of dosage 2.5 mg/L of sodium hypochlorite in 1 litter of harvested rainwater samples. Appendix F gives details of correlation and regression tests of FAC residuals versus contact time.

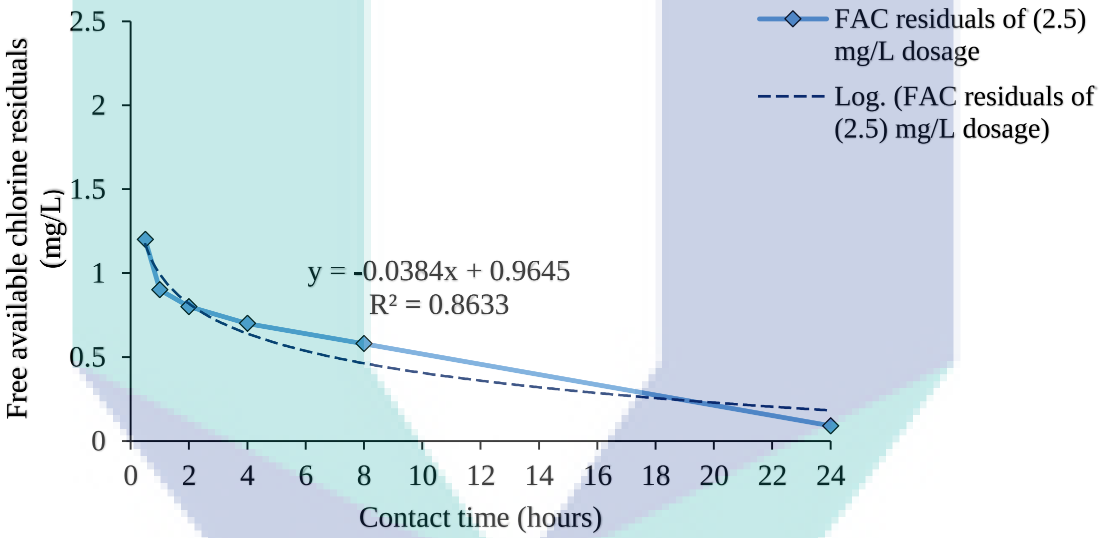

Figure 4.18 The concentration of FAC residuals of 2.5 mg/L versus contact time

Sodium hypochlorite solution of 3.5 mg/L dose concentration was added to rainwater samples. The average pH was 6.55 and average turbidity of the samples was 0.94 NTU while the average value of ammonia nitrogen was NH_3-N was 0.14 mg/L. Sodium hypochlorite concentration decayed within contact time and the *P* value of regression test is less than 0.05, R^2 of regression test equals to 98.0.9 % and for correlation equals to 93.1 % and r = - 0.96 of Pearson test which gives a strong correlation between FAC residuals decay and contacting time. The average values of FAC residuals equals to 1.71 mg/L after 30 minutes contacting time and it is less than 2 mg/L but the average of FAC residuals after 24 hours contact time equals to 0.15 mg/L and it is less than the minimum target of 0.2 mg/L so that it did not meet the requirements and this dose was not sufficient to achieve the objective. Figure 4.19 shows the average concentration values of FAC residuals versus contact time. Appendix F shows the details of regression and correlation tests of FAC residuals versus contact time.

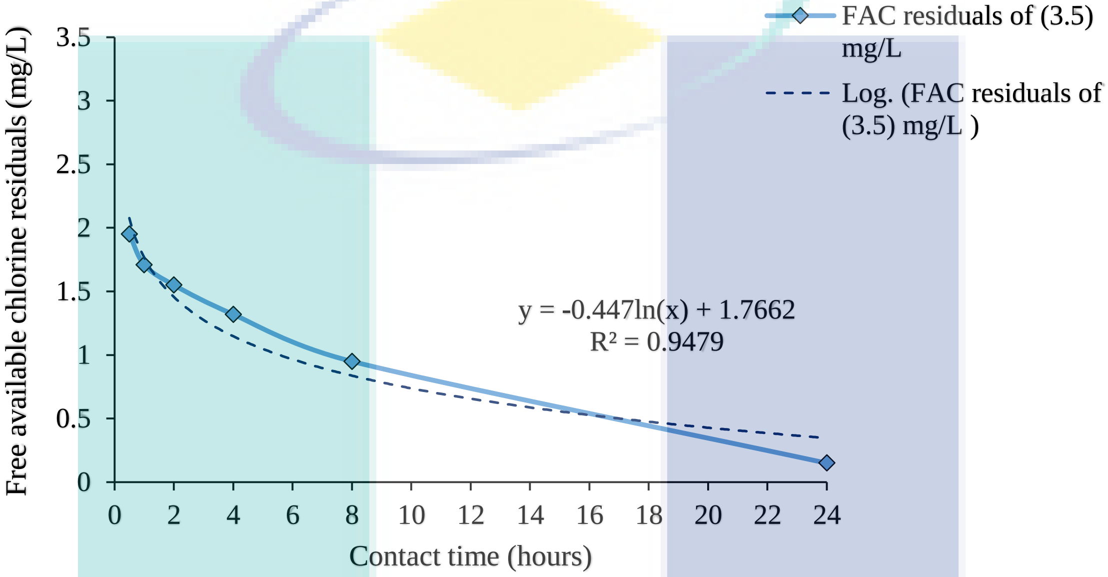

Figure 4.19 The concentration of FAC residuals of 3.5 mg/L versus contact time

A dosage of 4.0 mg/L of sodium hypochlorite solution were added to harvested rainwater samples to achieve FAC residuals of no more than 2 mg/L after 30 minutes contacting time and not less than 0.2 mg/L after 24 hours contact time period. The average residuals of FAC after 30 minutes contacting time were 1.85 mg/L and after 24 hours' reaction time the average residuals were 0.55 mg/L and that proves this dosage has achieved the target and meeting the disinfection requirements.

The average pH was 7.01, and average turbidity values were 0.97 NTU for tested rainwater samples and average NH_3-N was equals to 0.19 mg/L. The *P* value is less than 0.05 which is significant, R^2 of regression 99.76 % which shows a strong relation of residuals with contacting time and r = - 0.94 of Pearson test which indicates a significant correlation with contact time and when it increases and FAC residuals decrease. Figure 4.20 shows the concentration of FAC residuals versus contact time of 4.0mg/L dosage.

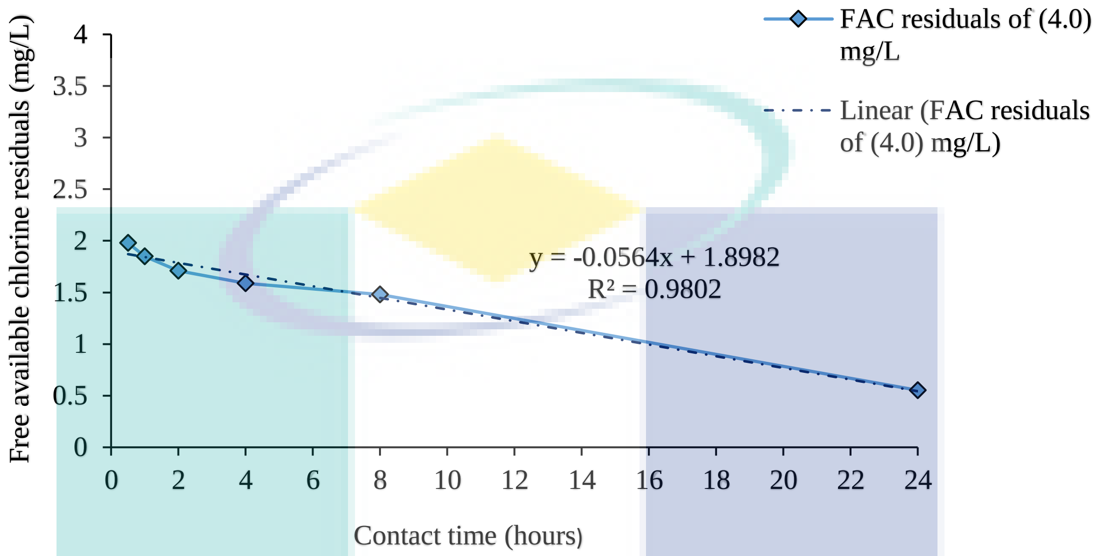

Figure 4.20 The concentration of FAC residuals of 4.0 mg/L versus contact time

A dosage of 4.5 mg/L sodium hypochlorite were added to 1 litter of each of harvested rainwater samples within contact time period minimum 0.5 hour and maximum 24 hours. The pH value was equal to 6.9, average temperature 25.5 ^{o}C and average turbidity equals to 0.89 NTU and average NH_3-N equals to 0.143 mg/L. FAC residuals after 30 minutes contacting time were 2.75 mg/L which is above the limits of 2mg/L and after 24 hours contacting time were 0.95 mg/L.

The *P* value equals to 0.002 and it is significantly below 0.05 and R^2 of regression test equals to 95.73 %, and Pearson r = - 0.96 which reflects a strong correlation between chlorine residuals decay and contacting time. Figure 4.21 demonstrates the FAC residuals concentration versus contacting time. Appendix F gives more details of regression and correlation tests of FAC residuals versus contact time.

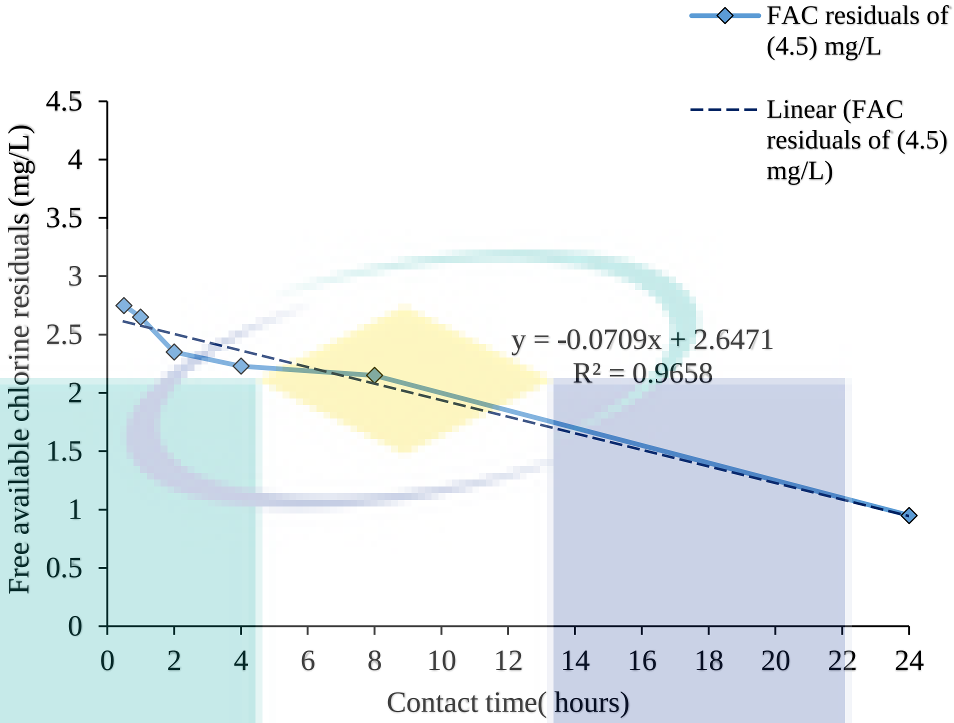

Figure 4.21 The concentration of FAC residuals of 4.5 mg/L versus contact time

Sodium hypochlorite solution with dosage concentration of 5 mg/L was added to 1 L of rainwater samples The pH value was equal to 6.67, average turbidity equals to 0.85 NTU, NH_3-N average equals to 0.066 mg/L and room temperature was 25.5 ^oC. FAC after 30 minutes contacting time were equal to 3.21 mg/L which exceeding the maximum target limits of 2mg/L and after 24 hours contacting time it was equal to 1.56 mg/L. Correlation and regression tests were applied for FAC residuals and R^2 of regression test value equals to 81.02 % and r = - 0.81 and *P* value was less than 0.05.

Figure 4.22 shows the FAC residuals concentration versus contacting time. Appendix F gives more details of regression and correlation tests of FAC residuals versus contact time.

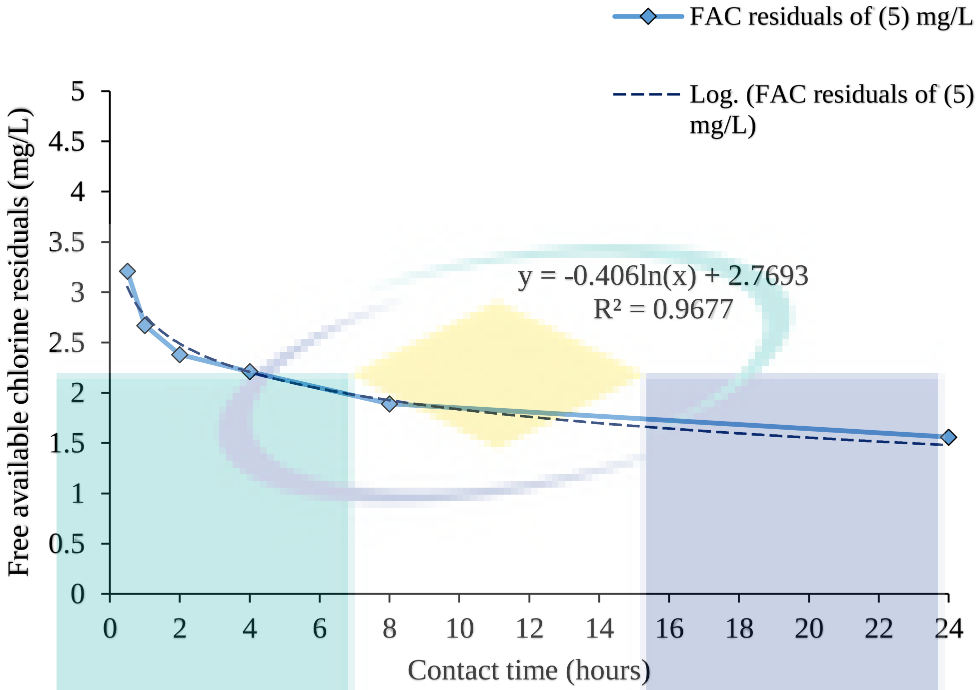

Figure 4.22 The concentration of FAC residuals of 5.0 mg/L versus contact time

4.4.2 Total Chlorine Residuals

Total chlorine residuals equals to that total of free available chlorine and combined chlorine residuals in water and it represents the remaining chlorine residuals in water after satisfying chlorine demand in water. Figure 4.23 shows the concentration of total chlorine versus contact time for each of sodium hypochlorite dose that have been added to rainwater samples (1.5, 2.5, 3.5, 4.0, 4.5 and 5.0 mg/L).

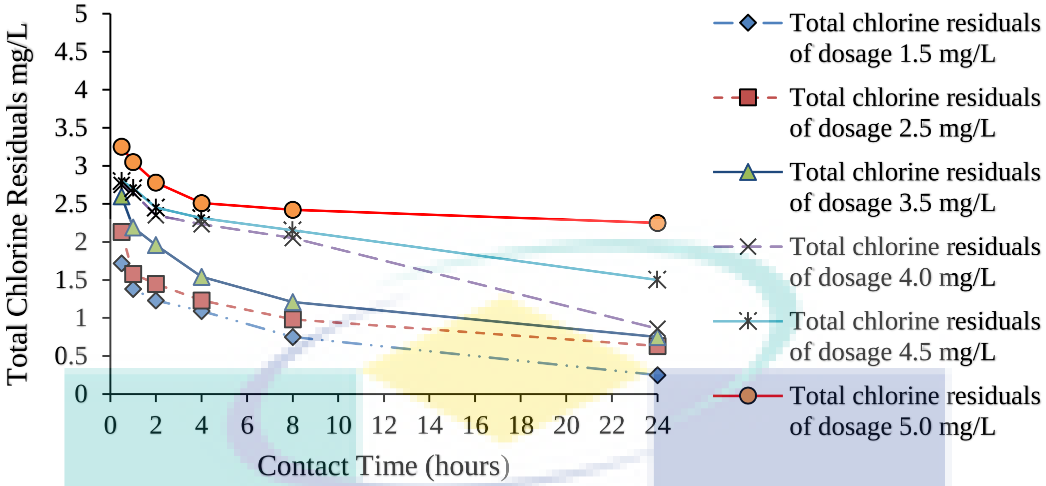

Figure 4.23 The concenrtation of total chlorine residuals versus contact time

4.4.3 Chlorine demand

Chlorine demand is defined as the amount of chlorine that added to water and the amount of chlorine that (free and combined) is remaining after a specific time and it used in reacting with various component of the water such as harmful organism and other organic and inorganic substances. The chlorine demand for all rainwater samples was satisfied and it depends on the presence of organic compounds that is absorbed by rainwater from atmosphere and surrounding environment and inorganic elements such as ammonia nitrogen and in this study the amount of ammonia nitrogen was so small and did not affect the chlorine demand process.

Figure 4.24 shows the chlorine demand versus contact time of the chlorine dosages that have been added to rainwater samples (1.5, 2.5, 3.5, 4.0,4.5 and 5.0 mg/L).

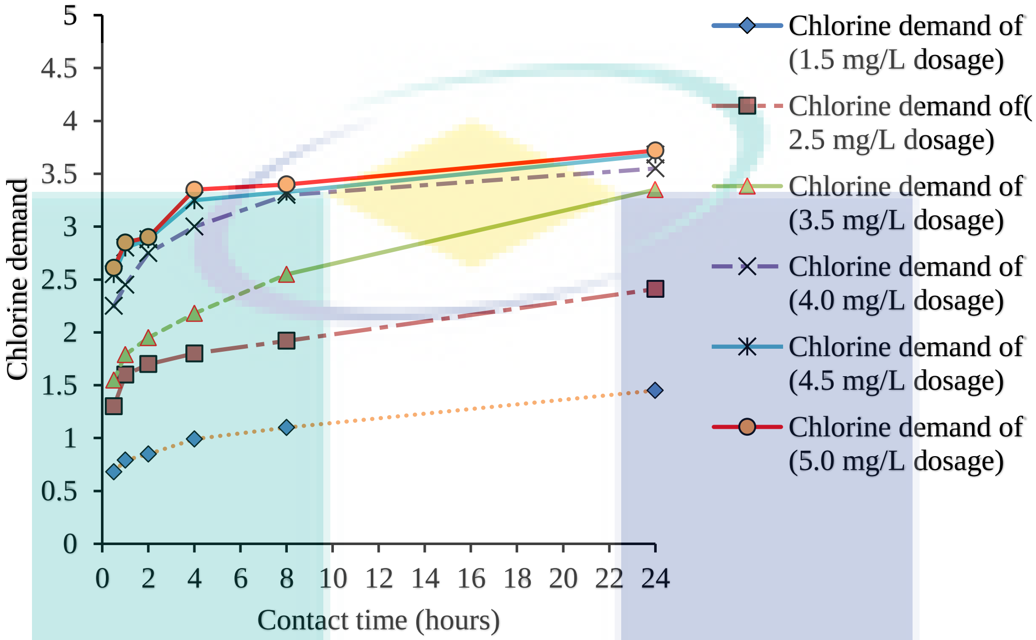

Figure 4.24 The chlorine demand versus contact time of sodium hypochlorite dosages

4.5 pH Values Before and After Chlorination Process

The values of pH for all rainwater samples were tested before and after the addition of sodium hypochlorite dosages to rainwater samples. As sodium hypochlorite solution was added to rainwater samples, pH increased for all rainwater samples and table 4.2 shows the comparison of average pH values before and after adding sodium hypochlorite solution to rainwater samples.

Table 4.3 Comparison of average pH values before and after adding sodium hypochlorite solution dosages to rainwear samples

Chlorine dosages	pH average values before chlorination	pH average values after chlorination
1.5	6.80	7.12
2.5	7.09	7.23
3.5	6.55	7.28
4.0	7.01	7.34
4.5	6.90	7.40
5.0	6.67	7.35

4.6 Ammonia Nitrogen Concentration before and after Chlorination

All rainwater samples were measured for ammonia nitrogen before dosing sodium hypochlorite solution to check the concentration of NH_3-N before adding the chlorine solution and after the chlorination process. The average concentration of ammonia nitrogen was very low for all rainwater samples and did not affect the chlorination process especially with higher dosages. pH average values increased after dosing chlorines because sodium hypochlorite solution is alkaline substance. The following table 4.3 shows the comparison of NH_3-N average values before and after chlorination process of rainwater samples.

Table 4.4 The comparison of the average NH_3-N values before and after chlorination

Chlorine dosages (mg/L)	NH_3-N average values before chlorination (mg/L)	NH_3-N average values after chlorination (mg/L)
1.5	0.076	0
2.5	0.086	0
3.5	0.143	0.001
4.0	0.091	0
4.5	0.21	0
5.0	0.21	0.002

4.7 The Effectiveness of Removing Rainwater Bacteria Contamination After Using Sodium Hypochlorite Solution for Disinfection

Rainwater samples were treated with different doses of sodium hypochlorite solution as designed experiment (1.5, 2.5, 3.5, 4.0, 4.5 and 5.0 mg/L). The effectiveness of each dose and efficiency was compared to standard limits that was appointed for the treatment of FAC residuals should not exceed 2 mg/L after 30 minutes' contact time and not less than 0.2 mg/L after 24 hours contact time. The microbiological test was applied to all treated samples to check the efficiency of sodium hypochlorite of each dose. The efficiency of each dose was compared according to the limitation standards of experiment design. Table 4.4 shows the efficiency of sodium hypochlorite solution within the designed dosages and the assessment for each dose within the limitations requirement for the experiment.

Table 4.5 The efficiency of sodium hypochlorite solution within the designed dosages and the assessments of each dose within limitations

Dosage mg/L	1.5	2.5	3.5
Efficiency	Not efficient , FAC residuals < 0.2 mg/L after 24 contact time	Not efficient, FAC residuals <0.2 mg/L after 24 hours contact time	Not efficient, FAC residuals < 0.2 mg/L after 24 hours contact time
Assessment	Not recommended	Not recommended	Not recommended
Dosage mg/L	4.0	4.5	5.0
Efficiency	Efficient, meet the requirements	Efficient	Efficient
Assessment	Recommended	Not recommended, FAC residuals > 2 mg/L after 30 minutes contact time	Not recommended, FAC residuals > 2 mg/L after 30 minutes contact time.

The efficiency chlorine doses were demonstrated in Table 4.5 as the 1.5 mg/L dosage did not meet the requirement and was not efficient because the FAC residuals equals to 0.05 mg/L and below 0.2 mg/L the minimum requirements after 24 hours contacting time which means the treated rainwater is not safe and the bacteria started growing back again and cause a microbiological contamination as the microbial test indicates the presence of *E. coli* results equals to 2 MPN/100 mL and total coliform equals to 3 MPN/100 mL. The 2.5 mg/L dose was not efficient since it did not meet the requirements as FAC residuals were less than 0.2 mg/L the minimum requirements after 24 hours contacting time and the rainwater treated samples were contaminated with *E. coli* and equals to 1 MPN/100 mL which indicates that the rainwater samples are not safe to consume.

The dosage of 3.5 mg/L did not meet the requirements as well as FAC residuals equals to 0.15 mg/L and less than the minimum requirement of 0.2 mg/L after 24 hours contact time even though the microbiological test of treated samples was equal to 0 for both *E. coli* and total coliform but the risk of water contamination again is quiet high and cannot be recommended for domestic purposes. The dosage of 4 mg/L was efficient and within the limitation requirements as FAC residuals equals to 0.55 mg/L after 24 hours contact time and the bacteria was equal to 0 of treated rainwater samples. While the doses of 4.5 mg/L and 5 mg/L were sufficient but not recommended because the FAC residuals for both doses exceeded the maximum recommendation limits of 2 mg/L after 30 minutes' contact time which caused unpleasant odder and test of chlorine in rainwater samples that cannot consumed.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Rainwater samples were collected from Water System for Rural Area WASRA rainwater harvesting system in Gambang during the period of pre-monsoon, monsoon and a post monsoon season. All samples were analysed according to standard procedures and their physicochemical parameters were determined. Based on physicochemical parameters that were tested, the majority of the mean of rainwater parameters for all three interval times of pre-monsoon and monsoon and post monsoon were within and below the allowable limits of drinking water guidelines standards of World Health Organization and Malaysia Drinking Water Quality Standards. pH mean values during seasonal changes of monsoon were all below drinking water quality standards and varied during seasonal changes as the lowest value was in pre-monsoon season 5.95 and the highest in monsoon 6.57 then 6.31 in post-monsoon and some samples were acidic but pH has no health effect on humans but can cause corrosion in rainwater system pipes and that can cause a leakage in rainwater harvesting system and pH values was varied significantly through seasons variation as well.

Alkalinity varied during seasonal changes while turbidity increased during monsoon seasonal changes the highest mean values were in post-monsoon while the lowest was in a pre-monsoon season and EC varied as well, salinity never change and TDS, TSS mean values were varied and DO increased during seasonal changes of monsoon, Cl increased and Zn, NH_3-N and Magnesium values were varied while Calcium mean values increased during seasonal changes. There was a significant variation among all physicochemical parameters during the seasonal changes of pre-monsoon, monsoon and post monsoon season. The variation of monsoon seasonal change was obvious on the physicochemical rainwater quality especially during heavy rain and the physicochemical parameters values varied according to that variation. However, all physicochemical parameters mean values were below drinking water quality standards. Rainwater samples indicated that they are heavily contaminated with pathogens and the microbiological rainwater quality through this study varied significantly through changing season of (pre-monsoon, monsoon and post-monsoon season). The presence of total coliform and *E. coli* bacteria in the majority of rainwater samples gives a big indicator that rainwater harvesting system is not suitable for human consumption use and for drinking purposes according to WHO and MDWQS without any treatment as the risk is so high for the human's health and the drinking guidelines standards stated that there should be zero pathogens per 100 mL for a safe drinking water purposes (WHO, 2011). *E. coli* is an indicator of fecal contamination and it can be used to indicate more recent contamination. The levels of total coliform and *E. coli* contamination varied through seasonal changes as the mean value of total coliform was 456.8 MPN/100 mL during post-monsoon and it decreased through monsoon to reach 249.78 MPN/100 mL and declined to 81.7 MPN/100 mL during post monsoon season, while *E. coli* concertation also varied through season changes as *E. coli* mean during pre-monsoon was very high equal to 12.087 MPN/100 mL then it decreased through monsoon and heavy rainy season to reach 9.030 MPN/100 mL and it decreased more during a pre-monsoon season to reach 5.012 MPN/100 mL which is the lowest value. However, the majority of rainwater samples were above the allowable limits of WHO drinking water standards and MDWQS.

The seasonal variation of the bacteria concentration during monsoon seasonal changes is so obvious and there was a significant variation in concertation levels of both total coliform and *E.coli* and this variation due to weather changes and the amount of rainfall, as in pre-monsoon seasons, less rain and high temperature beside the material of the tank encourage the bacteria to increase while in monsoon season the bacteria load was influenced by rainfall amount and decreased gradually while through post- monsoon was the lowest concentration of bacteria in rainwater harvesting tank. The main contamination of a roof surface is believed to come from the surrounding environment and occur due to deposit of fecal matter by small animals and birds that have access to the catchment surface also due to the airborne environmental contamination. Therefore, rainwater harvesting system needs a treatment to insure it is safe for human consumption use.

5. 2 Treatment of Rainwater Harvesting System with Sodium Hypochlorite Solution and the Suitability of Using it for Domestic Purposes

Chlorination treatment was applied to rainwater harvesting system in this study by using sodium hypochlorite solution with different doses to reach the optimum dose that satisfy disinfection requirements within the limitations that should be no more than 2.0 mg/L FAC residuals after 30 minutes contacting time to ensure water does not have unpleasant taste or odder and not less than 0.2 mg/L FAC residuals after 24 hours contact time to confirm that no pathogens exist and the water is safe for consumers. Therefor to satisfy the disinfection requirements, different doses of sodium hypochlorite solution were added to 1 litter of rainwater samples to reach the optimum dose within requirements with turbidity below 5 NTU and pH range 6.5-8. So that and based on these data and within the recommended proposed criteria for free available chlorine residuals to be not more than 2 mg/L after 30 minutes' contact time and not less than 0.2 mg/L 24 hours contact time after the treatment with sodium hypochlorite solution to be approved as a safe rainwater supply system and to be compatible with World Health Organization (WHO) recommendations for FAC residuals and (CDC), Centre of Diseases Control and Prevention. From the current results it is clear that 4 mg/L of NaOCl with concertation 15%.

This dosage is the appropriate and the optimum dose for rainwater harvesting system treatment with average pH 6.5-8 because it meets the requirement of disinfection as FAC residuals after 30 minutes' contact time is less than 2 mg/L and after 24 hours contact time equals to 0.55 mg/L which is more than the minimum recommendation of 0.2 mg/L. This dose provides a maximum concentration × time (C × T) factor of 59.4 mg-min/L and this factor is sufficient to inactivate many bacteria, viruses and protozoa that causes waterborne diseases if users wait after 30 minutes contacting time before consuming rainwater. This dose is significantly below the recommendation of United States Environmental Protection Agency USEPA for household drinking water purposes of 4.44 mg/L. Although disinfection and inactivation also depend on pH and temperature but in this study the temperature was ambient at 25 ^{o}C and pH was adjusted by adding a buffer of NaOH to rainwater samples. Although turbidity values were below 5 NTU but it is recommended to use filtration system before adding NaOCl to ensure to remove the oocyst. After applying the proper treatment for disinfection the rainwater is considered to be safe for domestic use and drinking purposes within the water quality recommendation standards.

5.3 Recommendations

According to the results and analysis that have been discussed earlier in this study and to improve the quality of the research and also to add an improvement to rainwater harvesting system (WASRA), the following recommendation can be taken into consideration in the future to overcome the difficulties in the study area.

i. For health safety reasons, the harvested rainwater should be treated with optimum chlorination dosage prior to use for drinking purposes by using automatically pump to control the dose within recommendation if possible.

ii. To minimize the contamination levels in rainwater harvesting system, cleaning the tank and use flushing out the remaining water towards the beginning of the monsoon season in addition to flush out the first rain event as a necessary action.

iii. To improve the quality of rainwater harvesting system, a screen wire mesh should be installed over to avoid and blocking into the gutters.

iv. Increasing the size of rainwater tank in WASRA rainwater harvesting system to increase the capacity of storage up to 5000 L.

v. Water should be abstracted using a proper functioning taps and a proper draining water collection should be maintained

vi. Monitoring the rainwater quality system for both physicochemical and microbial parameters should be applied and applying required maintenance to rainwater harvesting system.

vii. Health extension community workers should be training on maintaining good sanitary conditions of harvested rainwater system.

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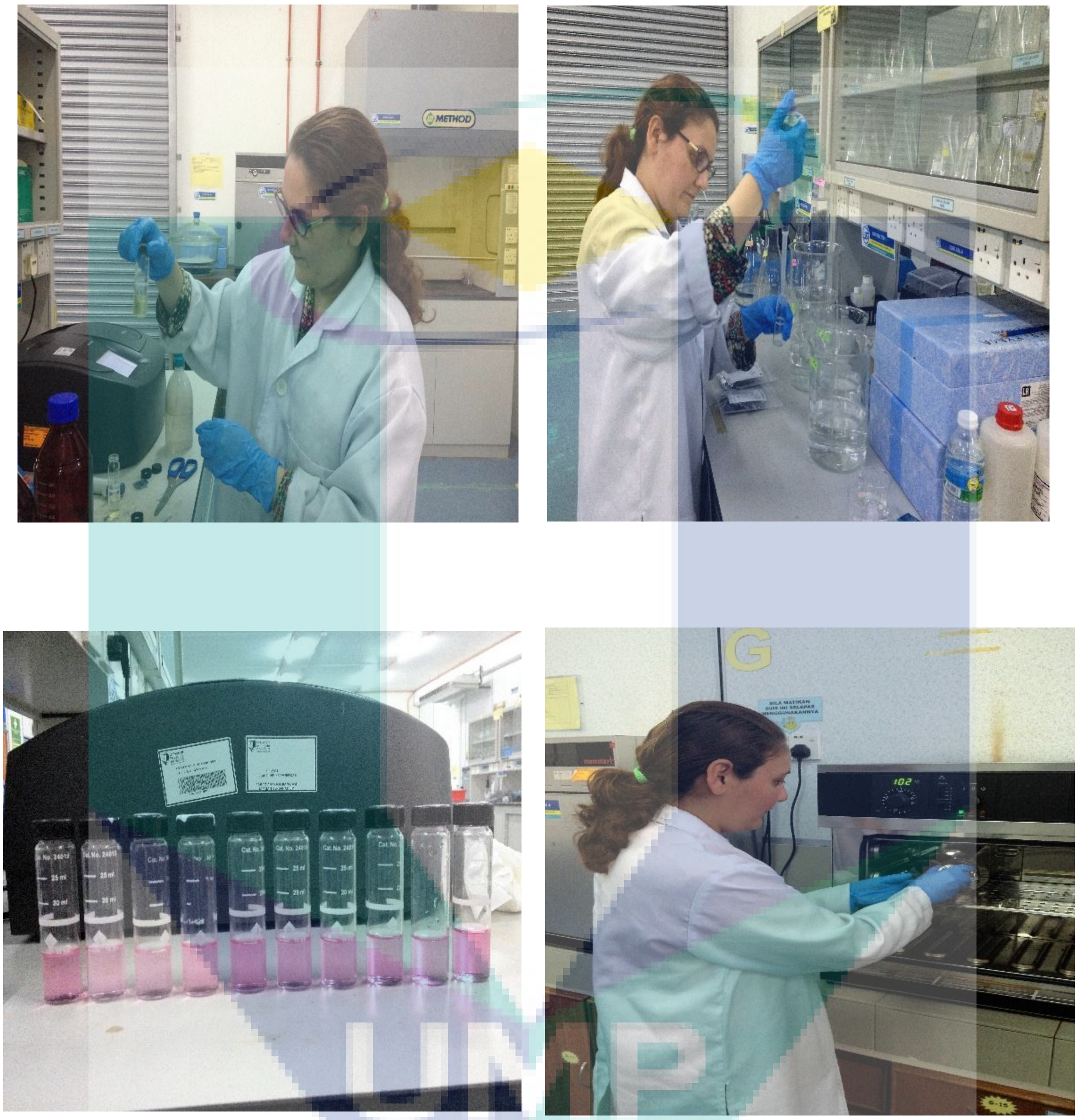
APPENDIX A



Photographs of Laboratory Experimental Tests

APPENDIX B

Normality Test Results of Physicochemical Parameters

Physiochemical Parameters	D	*P* value	alpha
Temperature	0.083	0.467	0.05
pH	0.116	0.128	0.05
Alkalinity	0.104	0.212	0.05
Turbidity	0.166	0.007	0.05
Salinity	0.071	0.210	0.05
TDS	0.065	0.253	0.05
TSS	0.100	0.012	0.05
DO	0.158	0.079	0.05
Conductivity	0.093	0.329	0.05
Hardness as Mg	0.145	0.0001	0.05
Hardness as Ca	0.082	0.027	0.05
Ammonia Nitrogen	0.244	0.0001	0.05

APPENDIX C

Descriptive Statistics of Physicochemical Parameters of Rainwater Samples

Parameter	Season	Mean	St. deviation	WHO	MDWQS
Temp. °C	Pre-monsoon Monsoon Post-monsoon	27.61 24.32 25.15	0.313 0.250 0.256	N/A	N/A
pH	Pre-monsoon Monsoon Post-monsoon	5.95 6.57 6.31	0.061 0.064 0.065	6.5-8.5	6.0-9.0
Alkalinity mgL^{-1}	Pre-monsoon Monsoon Post-monsoon	10.77 12.12 11.25	0.277 0.332 0.313	N/A	N/A
Turbidity NTU	Pre-monsoon Monsoon Post-monsoon	0.92 0.97 1.01	0.024 0.018 0.021	5	5
EC µS/cm	Pre-monsoon Monsoon Post-monsoon	64.23 49.22 45.73	1.310 1.265 1.359	1000	1000
Salinity o/00	Pre-monsoon Monsoon Post-monsoon	0 0 0	0 0 0	1.0	1.0
TDS mgL^{-1}	Pre-monsoon Monsoon Post-monsoon	45.26 47.01 43.05	0.485 0.860 0.581	600	1000

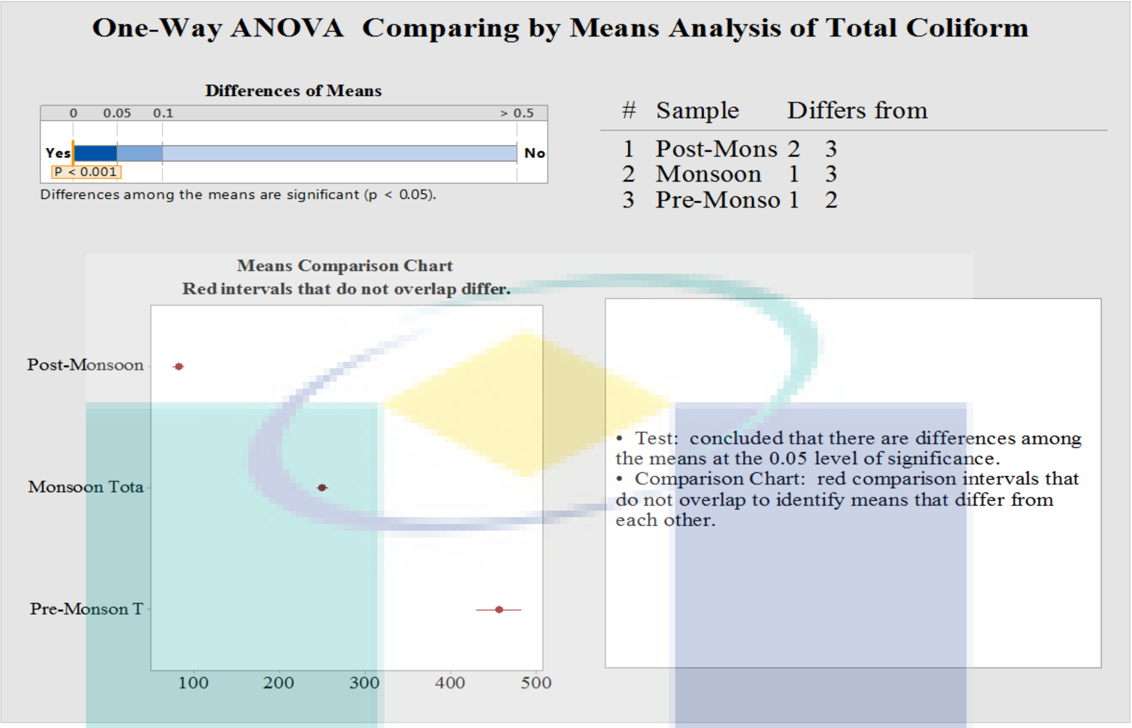
Table to be continued

Parameter	Season	Mean	St.deviation	WHO	MDWQS
TSS mgL^{-1}	Pre-monsoon	1.02	0.024	50	50
	Monsoon	1.05	0.017		
	Post monsoon	0.92	0.010		
DO mgL^{-1}	Pre-monsoon	7.11	0.072	8	5-8
	Monsoon	7.29	0.057		
	Post monsoon	7.53	0.027		
Cl mgL^{-1}	Pre-monsoon	0.30	0.025	250	300
	Monsoon	0.07	0.008		
	Post monsoon	0.06	0.004		
Zinc mgL^{-1}	Pre-monsoon	0.05	0.004	3	3
	Monsoon	0.05	0.007		
	Post monsoon	0.06	0.004		
NH_3 -N mgL^{-1}	Pre-monsoon	0.12	0.019	1.5	1.5
	Monsoon	0.03	0.003		
	Post monsoon	0.13	0.009		
Mg as $CaCO_3$ mgL^{-1}	Pre-monsoon	0.449	0.083	250	250
	Monsoon	0.31	0.029		
	Post monsoon	1.03	0.069		
Calcium $CaCO_3$ mgL^{-1}	Pre-monsoon	1.02	0.069	250	250
	Monsoon	0.77	0.054		
	Post monsoon	0.57	0.031		

APPENDIX D

Normality Distribution Test of Microbiological Parameters and One Way ANNOVA Analyses Results Comparing by Means

Microbiological parameters	W	*P* value	alpha
E. coli			
Pre-monsoon	0.963	0.204	0.05
Monsoon	0.957	0.131	0.05
Post-monsoon	0.861	0	0.05
Total coliform			
Pre-monsoon	0.961	0.197	0.05
Monsoon	0.963	0.448	0.05
Post-monsoon	0.960	0.531	0.05



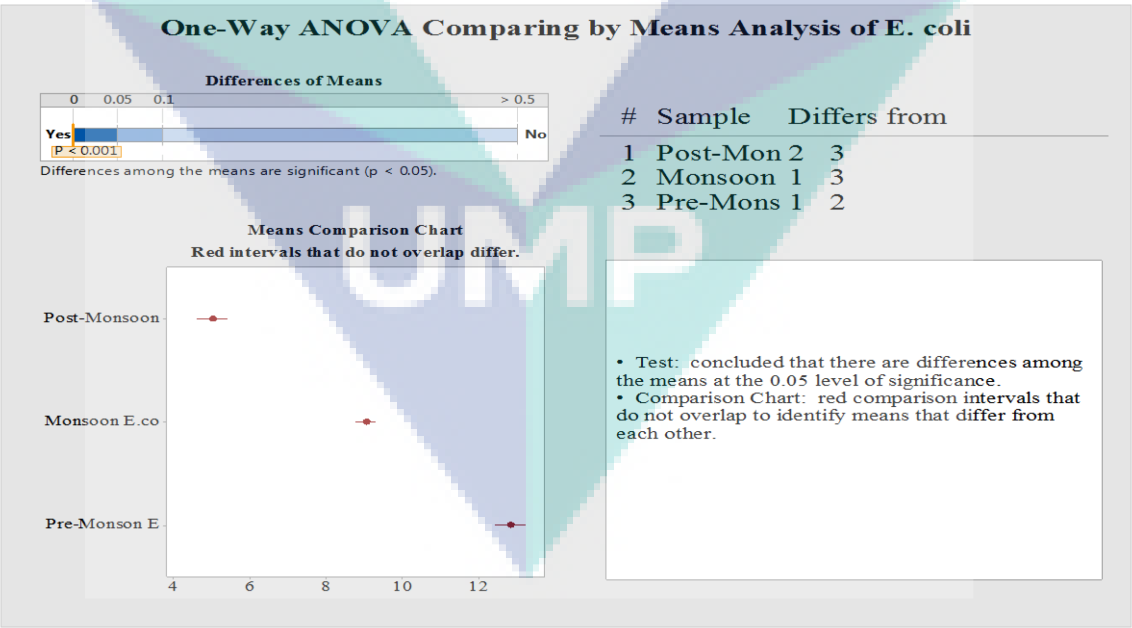
One-Way ANOVA Comparing by Means Analysis of Total Coliform

Differences among the means are significant (p < 0.05).

#	Sample	Differs from
1	Post-Mons	2 3
2	Monsoon	1 3
3	Pre-Monso	1 2

- Test: concluded that there are differences among the means at the 0.05 level of significance.
- Comparison Chart: red comparison intervals that do not overlap to identify means that differ from each other.

One-Way ANOVA Comparing by Means Analysis of total coliform



One-Way ANOVA Comparing by Means Analysis of E. coli

Differences among the means are significant (p < 0.05).

#	Sample	Differs from
1	Post-Mon	2 3
2	Monsoon	1 3
3	Pre-Mons	1 2

- Test: concluded that there are differences among the means at the 0.05 level of significance.
- Comparison Chart: red comparison intervals that do not overlap to identify means that differ from each other.

One-Way ANOVA Comparing by Means Analysis of total coliform

APPENDIX E

Quanti Tray 2000 Tables

#Large Wells Positive	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
0	<1	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.1	15.1	16.1	17.1	18.1	19.1	20.2	21.2	22.2	23.3	24.3
1	1.0	2.0	3.0	4.0	5.0	6.0	7.1	8.1	9.1	10.1	11.1	12.1	13.2	14.2	15.2	16.2	17.3	18.3	19.3	20.4	21.4	22.4	23.5	24.5	25.6
2	2.0	3.0	4.1	5.1	6.1	7.1	8.1	9.2	10.2	11.2	12.2	13.3	14.3	15.4	16.4	17.4	18.5	19.5	20.6	21.6	22.7	23.7	24.8	25.8	26.9
3	3.1	4.1	5.1	6.1	7.2	8.2	9.2	10.3	11.3	12.4	13.4	14.5	15.5	16.5	17.6	18.6	19.7	20.8	21.8	22.9	23.9	25.0	26.1	27.1	28.2
4	4.1	5.2	6.1	7.2	8.3	9.3	10.4	11.4	12.5	13.5	14.6	15.6	16.7	17.8	18.8	19.9	21.0	22.0	23.1	24.2	25.3	26.3	27.4	28.5	29.6
5	5.2	6.3	7.3	8.4	9.4	10.5	11.5	12.6	13.7	14.7	15.8	16.9	17.9	19.0	20.1	21.2	22.2	23.3	24.4	25.5	27.7	27.7	28.8	29.9	31.0
6	6.3	7.4	8.4	9.5	10.6	11.6	12.7	13.8	14.9	16.0	17.0	18.1	19.2	20.3	21.4	22.5	23.6	24.7	25.8	26.9	28.0	29.1	30.2	31.1	32.4
7	7.5	8.5	9.6	10.7	11.8	12.8	13.9	15.0	16.1	17.2	16.3	19.4	20.5	21.6	22.7	23.8	24.9	26.0	27.1	28.3	29.4	30.5	31.6	32.8	33.9
8	8.6	9.7	10.8	11.9	13.0	14.1	15.2	16.3	17.4	18.5	19.6	20.7	21.8	22.9	24.1	25.2	26.3	27.4	28.6	29.7	30.8	32.0	33.1	34.3	35.4
9	9.8	10.9	12.0	13.1	14.2	15.3	16.4	17.6	18.7	19.8	20.9	22.0	23.2	24.3	25.4	26.6	27.7	28.9	30.0	31.2	32.3	33.5	34.6	35.8	37.0
10	11.0	12.1	13.2	14.4	15.5	16.6	17.7	18.9	20.0	21.1	22.3	23.4	24.6	25.7	25.9	28.0	29.2	30.3	31.5	32.7	33.8	35.0	36.2	37.4	38.6
11	12.2	13.4	14.5	15.6	16.8	17.9	19.1	20.2	21.4	22.5	23.7	24.8	26.0	27.2	28.3	29.5	30.7	31.9	33.0	34.2	35.4	36.6	37.8	39.0	40.2
12	13.5	14.6	15.8	16.9	18.1	19.3	20.4	21.6	22.8	23.9	25.1	26.3	27.5	28.6	29.8	31.0	32.2	33.4	34.6	35.8	37.0	38.2	39.5	40.7	41.9
13	14.8	16.0	17.1	16.3	19.5	20.6	21.8	23.0	24.2	25.4	26.6	27.8	29.0	30.2	31.4	32.6	33.8	35.0	36.2	37.5	38.7	39.9	41.2	42.4	43.6
14	16.1	17.3	18.5	19.7	20.9	22.1	23.3	24.5	25.7	26.9	28.1	29.3	30.5	31.4	33.0	34.2	35.4	36.7	37.9	39.1	40.4	41.6	42.9	44.2	45.4
15	17.5	18.7	19.9	21.1	22.3	23.5	24.7	25.9	27.2	28.4	29.6	30.9	32.1	33.3	34.6	35.8	37.1	38.4	39.6	40.9	42.2	43.4	44.7	46.0	47.3
16	18.9	20.1	21.3	22.6	23.8	25.0	26.2	27.5	28.7	30.0	31.2	32.5	33.7	35.0	36.3	37.5	38.8	40.1	41.4	42.7	44.0	46.6	47.9	47.9	49.2
17	20.3	21.6	22.8	24.1	25.3	26.6	27.8	29.1	30.3	31.6	32.9	34.1	35.4	36.7	38.0	39.3	40.6	41.9	43.2	44.5	45.0	48.5	49.8	49.8	51.2
18	21.8	23.1	24.3	25.6	26.9	28.1	29.4	30.7	32.0	33.3	34.6	35.9	37.2	38.5	39.8	41.1	42.4	43.8	45.1	46.5	47.8	50.5	51.9	51.9	53.2
19	23.3	24.8	25.9	27.2	28.5	29.8	31.5	32.4	33.7	35.0	36.3	37.6	39.0	40.3	41.6	43.0	44.3	45.7	47.1	48.4	49.8	52.6	54.0	54.0	55.4
20	24.9	29.2	27.5	28.9	30.1	31.5	32.8	34.1	35.4	36.8	38.1	39.5	40.8	42.2	43.6	44.9	46.3	47.7	49.1	50.5	51.9	54.7	56.1	56.1	57.6
21	26.5	27.9	29.2	30.5	31.8	33.2	34.5	35.9	37.3	38.6	40.0	41.4	42.8	44.1	45.5	46.9	48.4	49.8	51.2	52.6	54.1	55.5	56.9	58.4	59.9
22	28.2	29.5	30.9	32.3	33.6	35.0	36.4	37.7	39.1	40.5	41.9	43.3	44.8	46.2	47.6	49.0	50.5	51.9	53.4	54.8	56.3	57.8	59.3	60.8	62.3
23	29.2	31.3	32.7	34.1	35.5	36.8	38.3	39.7	41.1	42.5	43.9	45.4	46.8	48.3	49.7	51.2	52.7	54.2	55.6	57.1	58.6	60.2	61.7	63.2	64.7
24	31.7	33.1	34.5	35.9	37.3	38.8	40.8	41.7	43.1	44.6	46.0	47.5	49.0	50.5	52.0	53.5	55.0	56.5	58.0	59.5	61.1	62.6	64.2	65.8	67.3
25	33.6	35.	36.4	37.9	39.3	40.8	42.2	43.7	45.2	46.7	48.2	49.7	51.2	52.7	54.3	55.8	57.3	58.9	60.5	62.2	63.6	65.2	66.6	68.4	70.0

Quanti Tray 2000 Tables

#Large Wells Positive	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
26	35.5	36.9	38.4	39.9	41.4	42.8	44.3	45.9	47.4	48.9	50.4	52.0	53.5	55.1	56.7	58.2	59.8	61.4	63.0	64.7	66.3	67.9	69.6	71.2	72.9
27	37.4	38.9	40.4	42.0	43.5	45.0	46.5	48.1	49.6	51.2	52.8	54.4	56.0	57.6	59.2	60.8	62.4	64.1	65.7	67.4	69.1	70.8	72.5	74.2	75.9
28	39.5	41.0	42.6	44.1	45.7	47.3	48.8	50.4	52.0	53.6	55.2	56.9	58.5	60.2	61.8	63.5	65.2	66.9	68.6	70.3	72.0	73.7	75.5	77.3	79.0
29	41.7	43.2	44.8	46.4	48.0	49.6	51.2	52.8	54.5	56.1	57.8	59.5	61.2	62.9	64.6	66.3	68.0	69.8	71.5	73.3	75.1	76.9	78.7	80.5	82.4
30	43.9	45.5	47.1	48.7	50.4	52.0	53.7	55.4	57.1	58.8	60.5	62.2	64.0	65.7	67.5	69.3	71.0	72.9	74.7	76.5	78.3	80.2	82.1	84.0	85.9
31	46.2	47.9	49.5	51.2	52.9	54.6	56.3	58.1	59.8	61.6	63.3	65.1	66.9	68.7	70.5	72.4	74.2	76.1	78.0	79.9	81.8	83.7	85.7	87.6	89.6
32	48.7	50.4	52.1	53.8	55.6	57.3	59.1	60.9	62.7	64.5	66.3	68.2	70.0	71.9	73.8	75.7	77.6	79.5	81.5	83.5	85.4	87.5	89.5	91.5	93.6
33	51.2	53.0	54.8	56.5	58.3	60.2	62.0	63.8	65.7	67.6	69.5	71.4	73.8	75.2	77.2	79.2	81.2	83.2	85.2	87.3	89.3	91.4	93.6	95.7	97.8
34	53.9	55.7	57.6	59.4	61.3	63.1	65.0	67.0	68.9	70.8	72.8	74.8	77.2	78.8	80.8	82.9	85.0	87.1	89.2	91.4	93.5	95.7	97.9	100.2	102.4
35	56.8	58,6	60.5	62.4	64.4	66.3	68.3	70.3	72.3	74.3	76.3	78.4	80.5	82.6	84.7	86.9	89.1	91.3	93.5	95.7	98.0	100.3	102.6	105.0	107.3
36	59.6	61.7	63.7	65.7	67.7	69.7	71.7	73.8	75.9	78.0	80.1	82.3	84.5	86.7	88.9	91.2	93.5	95.8	98.1	100.5	102.9	105.3	107.7	110.2	112.7
37	62.9	65.0	67.0	69.1	71.2	73.3	75.4	77.6	79.8	82.0	84.2	86.5	88.8	91.1	93.4	95.8	98.2	100.6	103.1	105.6	108.1	110.7	113.3	115.9	118.6
38	66.3	68.0	70.6	72.7	74.9	77.1	79.4	81.6	83.9	86.0	88.6	91.0	93.4	95.8	98.3	100.8	103.4	105.9	108.6	111.2	113.9	116.6	119.4	122.2	125.0
39	70.0	72.2	74.4	76.7	78.9	81.3	83.6	86.0	88.4	93.4	93.4	95.9	98.4	101.0	103.6	106.3	109.0	111.8	114.6	117.4	120.3	123.2	126.1	129.2	132.2
40	73.6	76.2	78.5	80.9	83.3	85.7	88.2	90.0	93.3	98.5	98.5	101.2	103.9	106.7	109.5	112.4	115.3	118.2	121.2	124.3	127.4	130.5	133.7	137.0	140.3
41	78.0	80.5	83.0	85.5	88.0	90.6	93.3	95.9	98.7	101.4	104.3	107.1	110.0	113.0	116.0	119.1	122.2	125.4	128.7	132.0	135.4	138.8	142.3	145.9	149.5
42	82.6	85.2	87.8	90.5	93.2	96.0	98.8	101.7	104.6	107.6	110.6	113.7	116.9	120.1	123.4	126.7	130.1	133.6	137.2	140.8	144.5	148.3	152.2	156.1	160.2
43	87.6	90.4	93.2	96.0	99.0	101.9	105/0	108.1	111.2	114.5	117.8	121.1	124.6	129.1	131.7	135.4	139.1	143.0	147.0	151.0	155.2	159.4	163.8	168.2	172.8
44	93.1	96.1	99.1	102.2	105.4	108.6	111.9	115.3	118.7	122.3	125.9	129.6	133.4	137.4	141.4	145.5	149.7	154.1	158.5	163.1	167.9	172.7	177.7	182.9	188.2
45	99.0	102.5	105.8	109.2	112.6	116.2	119.8	123.6	127.4	131.4	135.4	139.6	143.9	148.3	152.9	157.6	162.4	167.4	172.6	178.0	183.5	189.2	195.1	201.2	207.5
46	106.3	109.8	113.4	117.2	121.0	125.0	129.1	133.3	137.6	142.1	146.7	151.5	156.5	161.6	167.0	172.5	178.2	184.2	190.4	196.8	203.5	210.5	217.8	225.4	233.3
47	114.3	118.3	122.4	126.6	126.6	135.4	140.1	145.0	150.0	155.3	160.7	166.4	172.3	178.5	185.0	191.8	198.9	206.4	214.2	222.4	231.0	240.0	249.5	259.5	270.0
48	123.9	128.4	133.1	137.9	137.9	148.3	153.9	159.7	165.8	172.2	178.9	186.0	193.5	201.4	209.8	218.7	228.2	238.2	248.9	260.3	272.3	285.1	298.7	313.0	328.2
49	135.5	140.8	146.4	152.3	152.3	165.0	172.0	179.3	187.2	195.6	204.6	214.3	224.7	235.9	248.1	261.3	275.5	290.9	307.6	325.5	344.8	365.4	387.3	410.6	435.2

Quanti Tray 2000 Tables

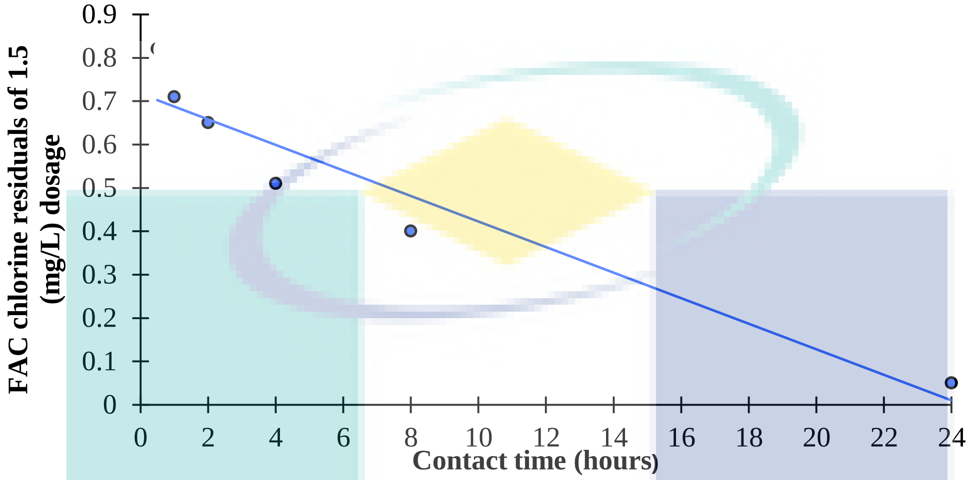
#Large Wells Positive	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
0	25.3	26.4	27.4	28.4	29.5	30.5	31.5	32.6	33.6	34.7	35.7	36.8	37.8	38.9	40.0	41.0	42.1	43.1	44.2	45.3	46.3	47.4	48.5	49.5
1	26.6	27.7	28.7	29.8	30.8	31.9	32.9	34.0	35.0	36.1	37.2	38.2	39.3	40.4	41.4	42.5	43.6	44.7	45.7	46.8	47.9	49.0	50.1	51.2
2	27.9	29.0	30.0	31.1	32.5	33.2	34.3	35.4	36.5	37.5	38.6	39.7	40.8	41.9	43.0	44.0	45.1	46.2	47.3	48.4	49.5	50.6	51.7	52.8
3	29.3	30.4	31.4	32.5	33.6	34.7	35.8	36.8	37.9	39.0	40.1	41.2	42.3	43.4	44.5	45.6	46.7	47.8	48.9	50.0	51.2	52.3	53.4	54.5
4	30.7	31.8	32.8	33.9	35.0	36.1	37.2	38.3	39.4	40.5	41.6	42.8	43.9	45.0	46.1	47.2	48.3	49.5	50.6	51.7	52.9	54.0	55.1	56.3
5	32.1	33.2	34.3	35.4	36.5	37.6	38.7	39.9	41.0	42.1	43.2	44.4	45.5	46.6	47.7	48.9	50.0	51.2	52.3	53.5	54.5	55.8	56.9	58.1
6	33.5	34.7	35.8	36.9	38.0	39.2	40.3	41.4	42.6	43.7	44.8	46.0	47.1	48.3	49.4	50.6	51.7	52.9	54.1	55.2	56.4	57.6	58.7	59.9
7	35.0	36.2	37.3	38.4	39.6	40.7	41.9	43.0	44.2	45.3	46.6	47.7	48.8	50.0	51.2	52.3	53.5	54.7	55.9	57.1	58.3	59.4	60.6	61.8
8	36.6	37.7	38.9	40.0	41.2	42.3	43.5	44.7	45.9	47.0	48.2	49.4	50.6	51.8	53.0	54.1	55.3	56.5	57.7	59.0	60.2	61.4	62.6	63.8
9	38.1	39.3	40.5	41.6	42.8	44.0	45.2	46.4	47.6	48.8	50.0	51.2	52.4	53.6	54.8	56.0	57.2	58.4	59.7	60.9	62.1	63.4	64.6	65.8
10	39.7	40.9	42.1	43.3	44.5	45.7	46.9	48.1	49.3	50.6	51.8	53.0	54.2	55.5	56.7	57.9	59.2	60.4	61.7	62.9	64.2	65.4	66.7	67.9
11	41.4	42.6	43.8	45.0	46.3	47.5	48.7	49.9	51.2	52.4	53.7	54.9	56.1	57.4	58.6	59.9	61.2	62.4	63.7	65.0	66.3	67.5	68.8	70.1
12	43.1	44.3	45.6	46.8	48.1	49.3	50.6	51.8	53.1	54.3	55.6	56.8	58.1	59.4	60.7	62.0	63.2	64.5	65.8	67.1	68.4	69.7	71.0	72.4
13	44.9	46.1	47.4	48.6	49.9	51.2	52.5	53.7	55.0	56.3	57.6	58.9	60.2	61.5	62.8	64.1	65.4	66.7	68.0	69.3	70.7	72.0	73.3	74.7
14	46.7	48.0	49.3	50.5	51.8	53.1	54.4	55.7	57.0	58.3	59.6	60.9	62.3	63.6	64.9	66.3	67.6	68.9	70.3	71.6	73.0	74.4	75.7	77.1
15	48.6	49.9	51.2	52.5	53.6	55.1	56.4	57.8	59.1	60.4	61.8	63.1	64.5	65.8	67.2	68.5	69.9	71.3	72.6	74.0	75.4	76.8	78.2	79.6
16	50.5	51.8	53.2	54.5	55.8	57.2	58.5	59.9	61.2	62.6	64.0	65.3	66.7	68.1	69.5	70.9	72.3	73.7	75.1	76.5	77.9	79.3	80.8	82.2
17	52.5	53.9	55.2	56.6	58.0	59.3	60.7	62.1	63.5	64.9	66.3	67.7	69.1	70.5	71.9	73,3	74.8	76.2	77.6	79.1	80.5	82.0	83.5	84.9
18	54.6	56.0	57.4	58.8	60.2	61.6	63.0	64.4	65.8	67.2	68.6	70.1	71.5	73.0	74.4	75.9	77.3	78.8	80.3	81.8	83.3	84.8	86.3	87.8
19	56.8	58.2	59.6	61.0	62.4	63.9	65.3	66.8	68.2	69.7	71.1	72.6	74.1	75.5	77.0	78.5	80.0	81.5	83.1	84.6	86.1	87.6	89.2	90.7
20	59.0	60.4	61.9	63.3	64.8	66.3	66.3	69.2	70.7	72.2	73.7	75.2	76.7	78.2	79.8	81.3	82.8	84.4	85.9	87.5	89.1	90.7	92.2	93.8
21	61.3	62.8	64.3	65.8	67.3	68.8	70.3	71.8	73.3	74.9	76.4	77.9	79.5	81.1	82.6	84.2	85.8	87.4	89.0	90.6	92.2	93.8	95.4	97.1
22	63.8	65.3	66.8	68.3	69.8	71.4	72.9	74.5	76.1	77.6	79.2	80.8	82.4	84.0	85.6	87.2	88.9	90.5	92.1	93.8	95.5	97.1	98.8	100.5
23	66.3	67.8	69.4	71.0	72.5	74.1	75.7	77.3	78.9	80.5	82.2	83.8	85.4	87.1	88.7	90.4	92.1	93.8	95.5	97.2	98.9	100.6	102.4	104.1
24	68.9	70.5	72.1	73.7	75.3	77.0	78.6	80.3	81.9	83.6	85.2	86.9	88.6	90.3	92.0	93.8	95.5	97.2	99.0	100.7	102.5	104.3	106.1	107.9
25	71.7	73.3	75.0	76.6	78.3	80.0	81.7	83.3	85.1	86.8	88.5	90.2	92.0	93.7	95.5	97.3	99.1	100.9	102.7	104.5	106.3	108.2	110.0	111.9

Quanti Tray Tables 2000

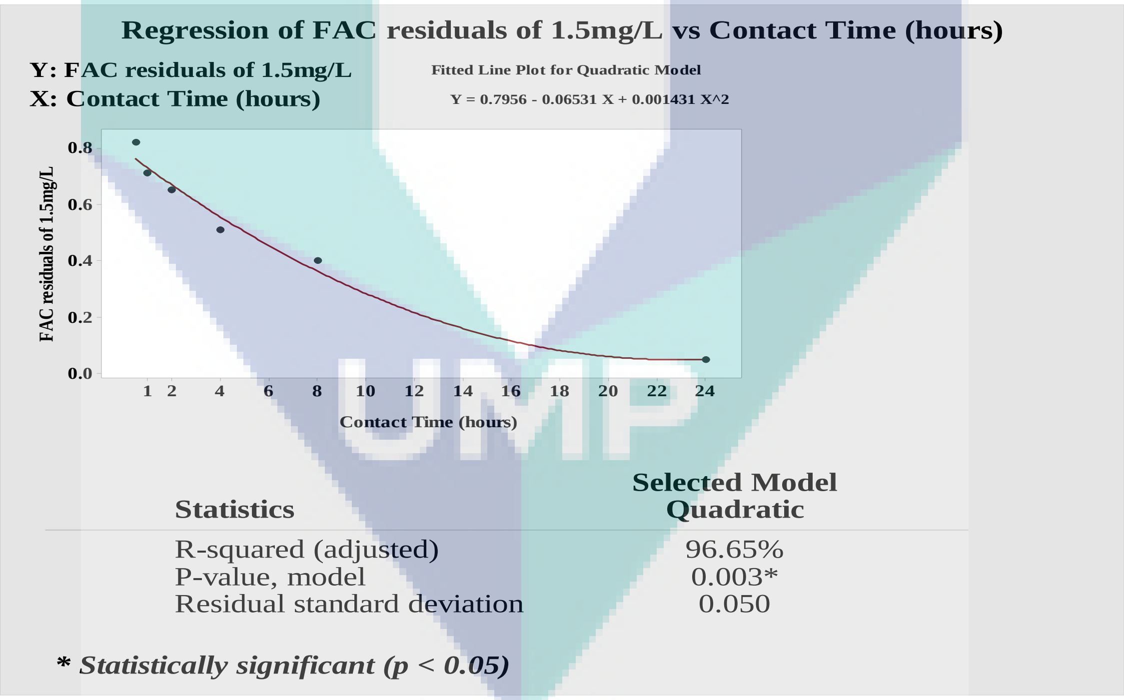
#Large Wells Positive	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
26	74.6	76.3	78.0	79.7	81.4	83.1	84.8	88.4	88.4	90.1	91.9	93.7	95.5	97.3	99.2	101.0	102.9	104.7	106.6	108.5	110.4	112.3	114.2	116.2
27	77.6	79.4	81.1	82.9	84.6	86.4	88.2	91.9	91.9	93.7	95.5	97.4	99.3	101.2	103.1	105.0	106.9	108.8	110.8	112.7	114.7	116.7	118.7	120.7
28	80.8	82.6	84.4	86.3	88.1	89.9	91.8	95.6	95.6	97.5	99.4	101.3	103.3	105.2	107.2	109.2	111.2	113.2	115.2	117.3	119.3	121.4	123.5	125.6
29	84.2	86.1	87.9	89.8	91.7	93.7	95.6	99.5	99.5	101.5	103.5	105.5	107.5	109.5	111.6	113.7	115.7	117.8	120.0	122.1	124.2	126.4	128.6	130.8
30	87.8	89.7	91.7	93.6	95.6	97.6	99.6	103.7	103.7	105.7	107.8	109.9	112.0	114.2	116.3	118.5	120.6	122.8	125.1	127.3	129.5	131.8	134.1	136.4
31	91.6	93.6	95.6	97.7	99.7	101.8	103.9	106.0	108.2	110.3	112.5	114.7	116.9	119.1	121.4	123.6	125.9	128.2	130.5	132.9	135.3	137.7	140.1	142.5
32	95.7	97.8	99.9	102.0	104.2	106.3	108.5	110.7	113.0	115.2	117.5	119.8	122.1	124.5	126.8	129.2	131.6	134.0	136.5	139.0	141.5	144.0	146.6	149.1
33	100.0	102.2	104.4	106.6	108.9	111.2	113.5	115.8	118.2	120.5	122.9	125.4	127.8	130.3	132.8	135.3	137.8	140.0	143.0	145.6	148.3	150.0	153.7	156.4
34	104.7	107.0	109.3	111.7	114.0	116.4	118.9	121.3	123.8	126.3	128.8	131.4	134.0	136.6	139.2	141.9	144.6	147.4	150.1	152.9	155.7	158.6	161.5	164.4
35	109.7	112.2	114.6	117.1	119.6	122.2	124.7	127.3	129.9	132.6	135.3	138.0	140.8	143.6	146.4	149.2	152.1	155.0	158.0	161.0	164.0	167.1	170.2	173.3
36	115.2	117.8	120.4	123.0	125.7	128.4	131.1	133.9	136.7	139.5	142.4	145.3	148.3	151.3	154.3	157.3	160.5	163.6	166.8	170.0	173.3	176.6	179.9	183.3
37	121.3	124.0	126.8	129.6	132.4	135.3	138.2	141.2	144.2	147.3	150.3	153.5	156.7	159.9	163.1	166.5	169.8	173.2	176.7	180.2	183.7	187.3	191.0	194.7
38	127.9	130.8	133.8	136.8	139.9	143.0	146.2	149.4	152.6	155.9	159.2	162.6	166.1	169.6	173.2	176.8	180.4	184.2	188.0	191.8	195.7	199.7	203.7	207.7
39	135.3	138.5	141.7	145.0	148.3	151.7	155.1	158.6	162.1	165.7	169.4	173.1	176.9	180.7	184.7	188.7	192.7	196.8	201.0	205.3	209.6	214.0	218.5	223.0
40	143.7	147.1	150.6	154.2	157.8	161.5	165.3	169.1	173.0	177.0	181.1	185.2	189.4	193.7	198.1	202.5	207.1	211.7	216.4	221.1	226.0	231.0	236.0	241.1
41	153.2	157.0	160.9	164.8	168.9	173.0	177.2	181.5	185.8	190.3	194.8	199.5	204.2	209.1	214.0	219.1	224.2	229.4	234.8	240.2	245.8	251.5	257.2	263.1
42	164.3	168.6	172.9	177.3	181.9	186.5	191.3	196.1	201.1	206.2	211.4	216.7	222.2	227.7	233.4	239.2	245.2	251.3	257.5	263.8	270.3	276.9	283.6	290.5
43	177.5	182.3	187.3	192.4	197.6	202.9	208.4	214.0	219.8	225.8	231.8	238.1	244.5	251.0	257.7	264.6	271.7	278.9	286.3	293.8	301.5	309.4	317.4	325.7
44	193.5	199.3	205.1	211.0	217.2	223.5	230.0	236.7	243.6	250.8	258.1	265.6	273.3	281.2	289.4	297.8	306.3	315.1	324.1	333.3	342.8	352.4	362.3	372.4
45	214.1	220.9	227.9	235.2	224.7	250.4	258.4	266.7	275.3	284.1	293.3	302.6	312.3	322.3	332.5	343.0	353.8	364.9	376.2	387.9	399.8	412.0	424.5	437.4
46	241.5	250.0	258.9	268.2	277.8	287.8	298.1	308.8	319.9	331.4	343.3	355.5	368.1	381.1	349.5	408.3	422.5	437.1	452.0	467.4	483.3	499.6	516.3	533.5
47	280.9	292.4	304.4	316.9	330.0	343.6	357.8	372.5	387.7	403.4	419.8	436.6	454.1	472.1	490.7	509.9	529.8	550.4	571.7	593.8	616.7	640.5	665.3	691.0
48	344.1	360.9	378.4	396.8	416.0	436.0	456.9	478.6	501.2	524.7	549.3	574.8	601.5	629.4	658.6	689.3	721.5	755.6	791.5	829.7	870.4	913.9	960.6	1011
49	461.1	488.4	517.2	547.5	547.5	613.1	648.8	686.7	727.0	770.1	816.4	866.4	920.8	980.4	1046.2	1119.9	1203.3	1299.7	1413.6	1553.1	1732.9	1986.3	2419.6	>2419

APPENDIX F

Correlation and Regression Tests of FAC Residuals Versus Contact Time



The correlation relation between FAC residuals and contact time of 1.5 mg/L dosage



Regression of FAC residuals of 1.5mg/L vs Contact Time (hours)

Y: FAC residuals of 1.5mg/L
X: Contact Time (hours)

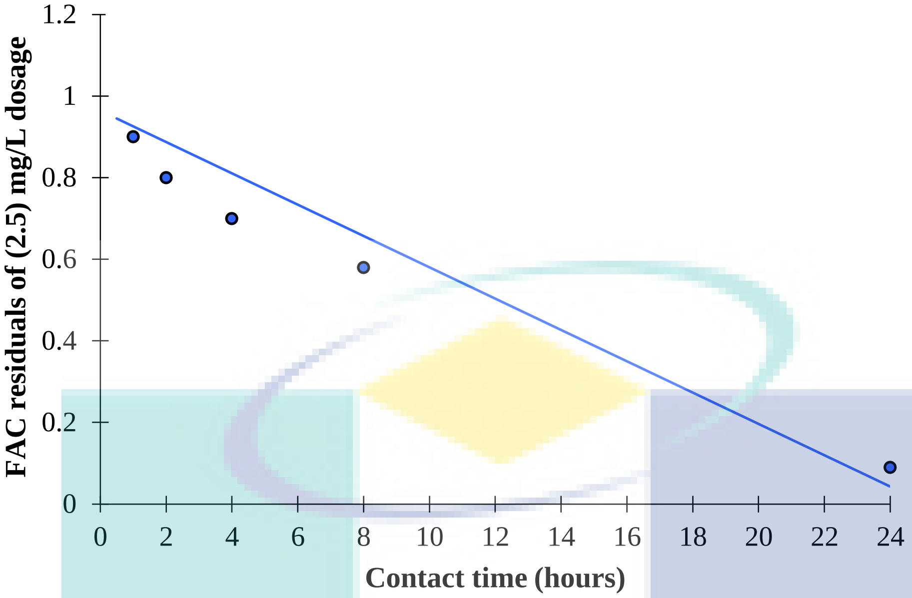
Fitted Line Plot for Quadratic Model

$Y = 0.7956 - 0.06531 X + 0.001431 X^2$

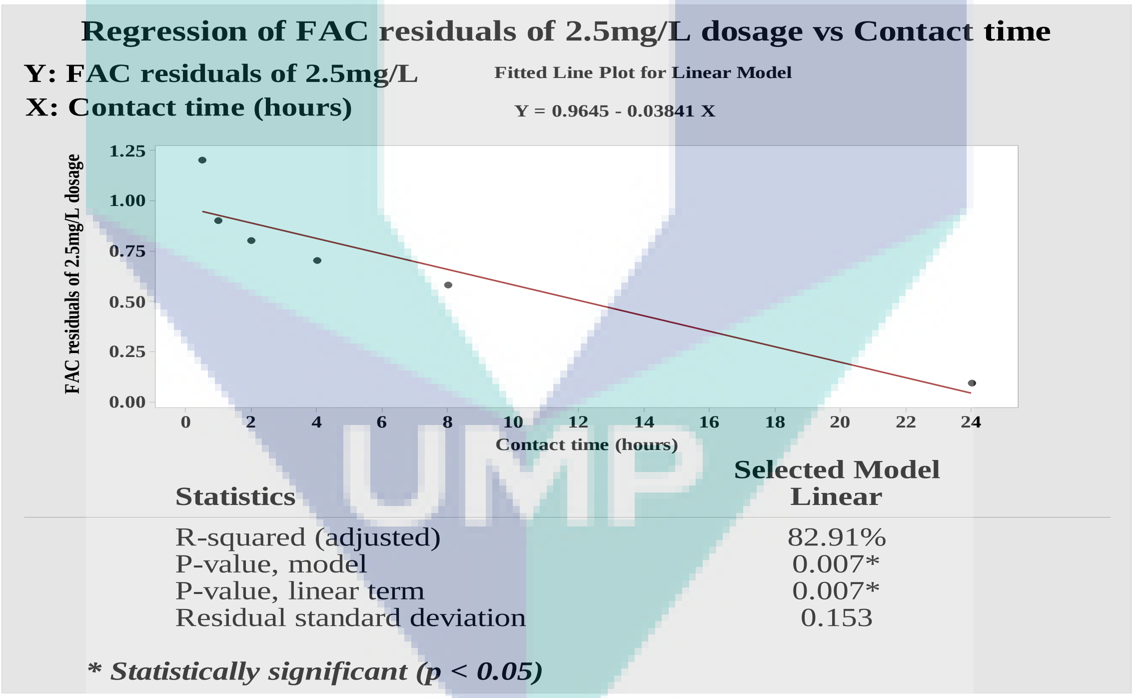
Statistics	**Selected Model Quadratic**
R-squared (adjusted)	96.65%
P-value, model	0.003*
Residual standard deviation	0.050

**** Statistically significant (p < 0.05)***

The regression model of FAC residuals versus time of 1.5 mg/L dosage



The correlation relation between FAC residuals and contact time of 2.5 mg/L dosage



Regression of FAC residuals of 2.5mg/L dosage vs Contact time

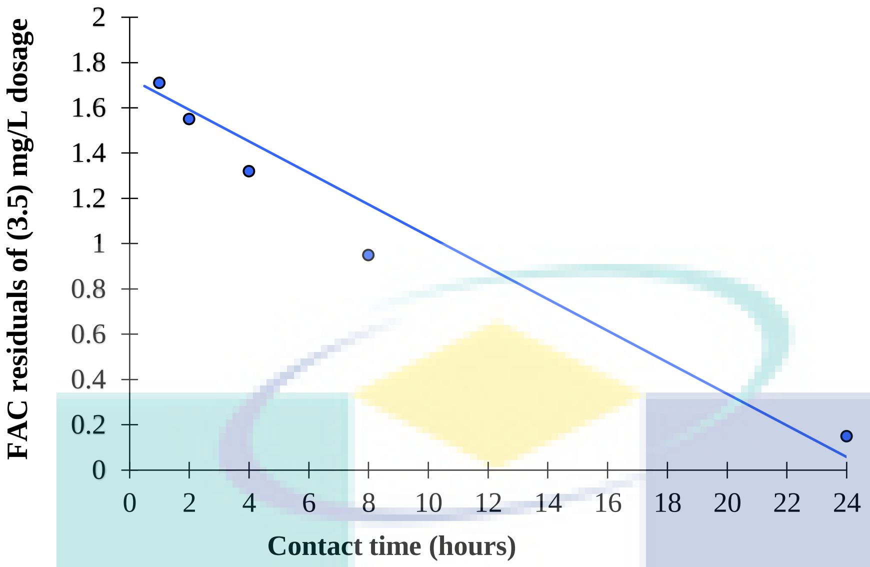
Y: FAC residuals of 2.5mg/L

X: Contact time (hours)

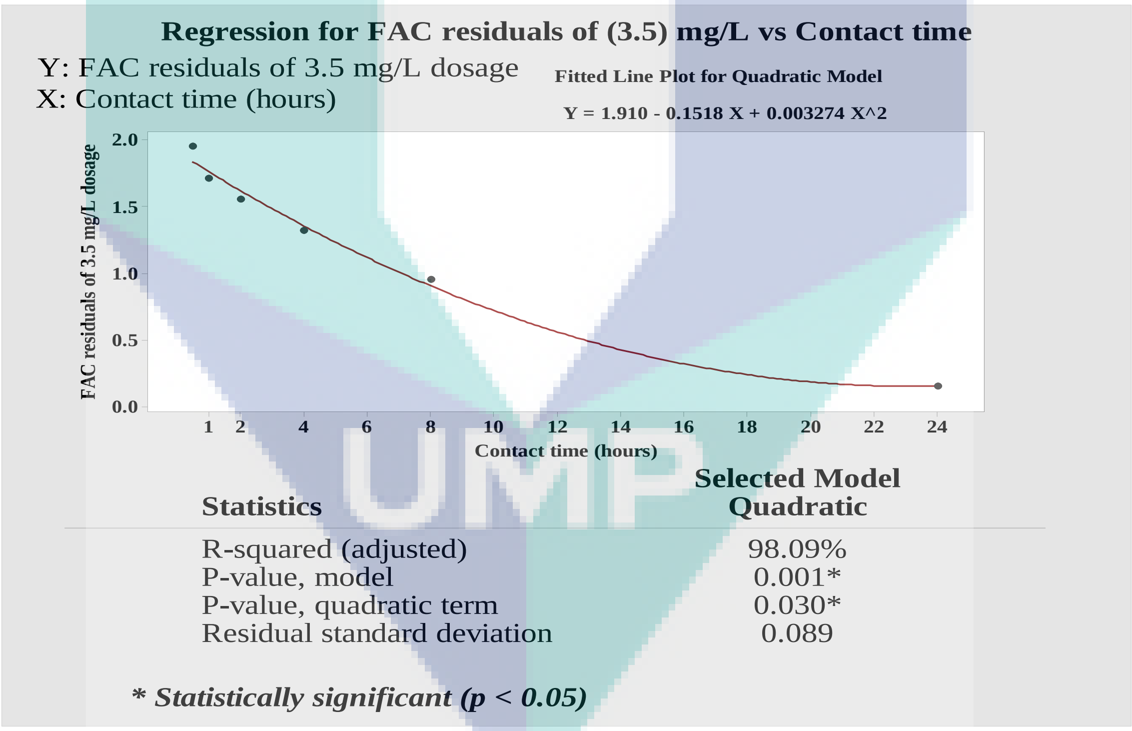
Statistics	Selected Model Linear
R-squared (adjusted)	82.91%
P-value, model	0.007*
P-value, linear term	0.007*
Residual standard deviation	0.153

***** Statistically significant (p < 0.05)***

The regression of FAC residuals versus contact time of 2.5 mg/L dosage



The correlation relation between FAC residuals and contact time of 3.5 mg/L dosage



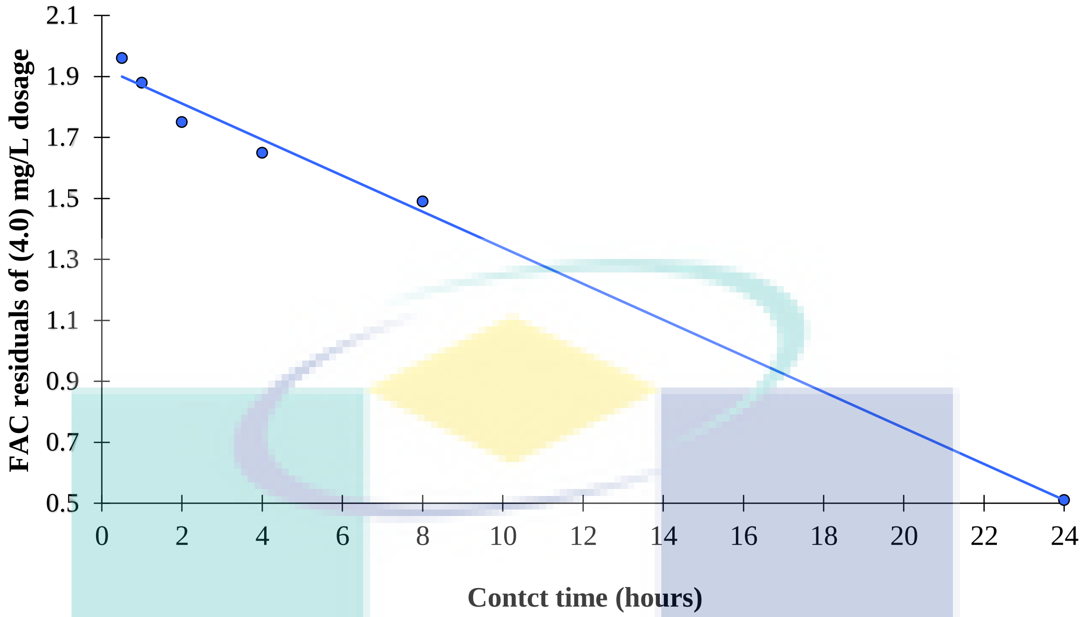
Regression for FAC residuals of (3.5) mg/L vs Contact time

Y: FAC residuals of 3.5 mg/L dosage
X: Contact time (hours)

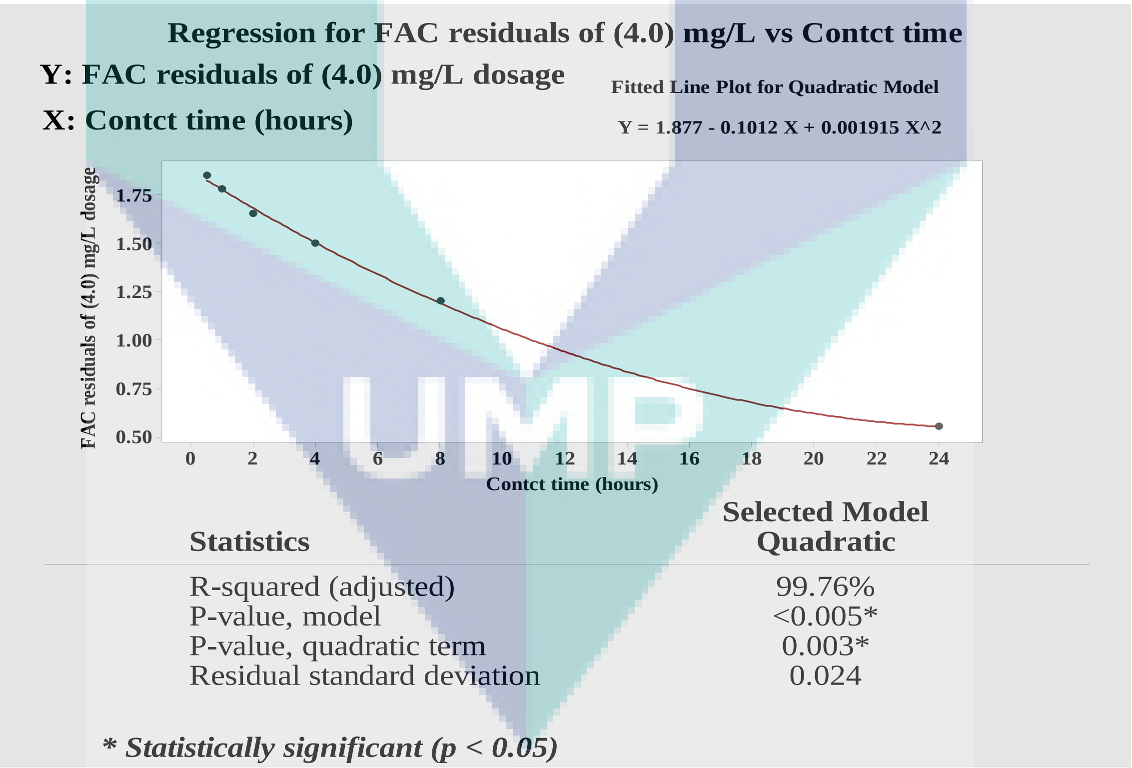
Statistics	Selected Model Quadratic
R-squared (adjusted)	98.09%
P-value, model	0.001*
P-value, quadratic term	0.030*
Residual standard deviation	0.089

*** Statistically significant ($p < 0.05$)***

The regression of FAC residuals versus contact time of 3.5 mg/L dosage



The correlation relation between FAC residuals and contact time of 4.0 mg/L dosage



Regression for FAC residuals of (4.0) mg/L vs Contct time

Y: FAC residuals of (4.0) mg/L dosage

X: Contct time (hours)

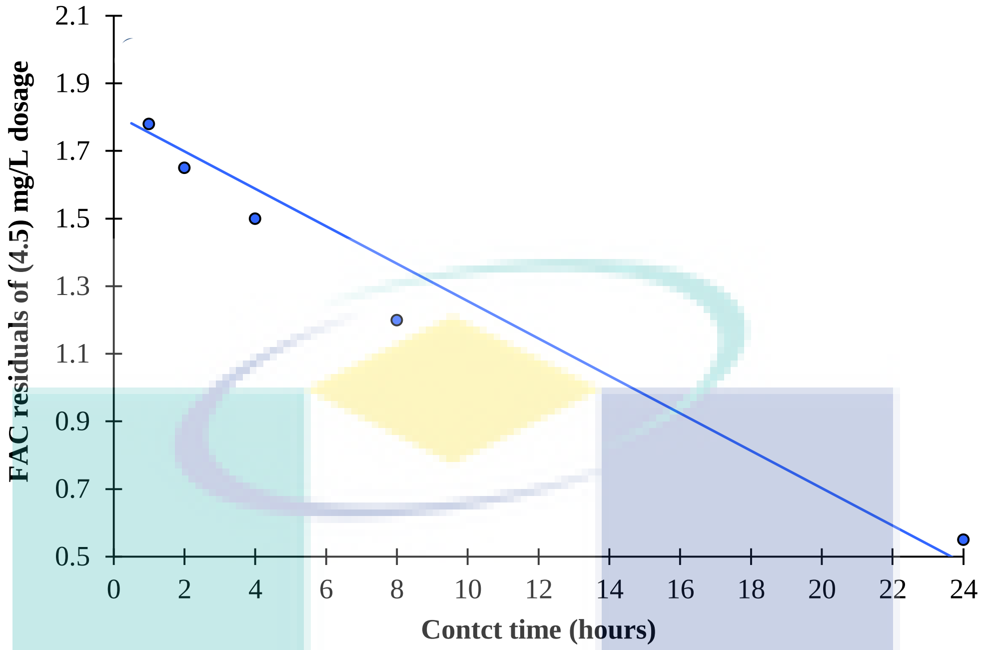
Fitted Line Plot for Quadratic Model

$Y = 1.877 - 0.1012 X + 0.001915 X^2$

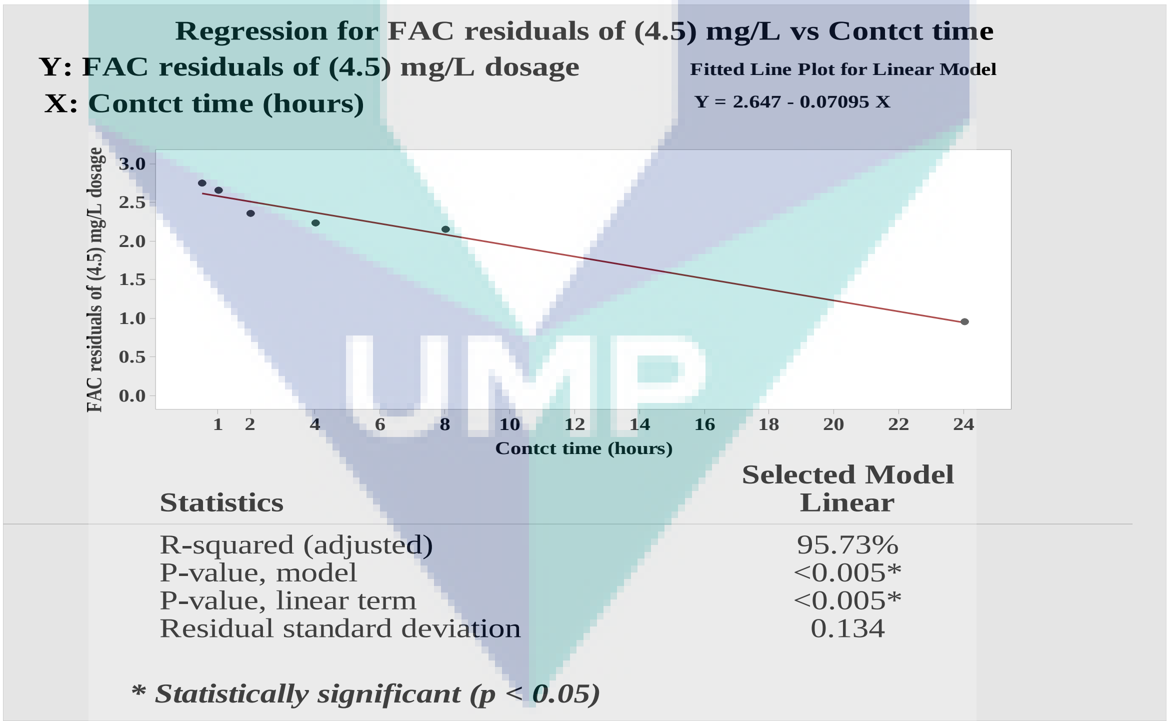
Statistics	Selected Model Quadratic
R-squared (adjusted)	99.76%
P-value, model	<0.005*
P-value, quadratic term	0.003*
Residual standard deviation	0.024

** Statistically significant ($p < 0.05$)*

The regression of FAC residuals versus contact time of 4.0 mg/L dosage



The correlation relation between FAC residuals and contact time of 4.5 mg/L dosage


Regression for FAC residuals of (4.5) mg/L vs Contct time

Y: FAC residuals of (4.5) mg/L dosage

X: Contct time (hours)

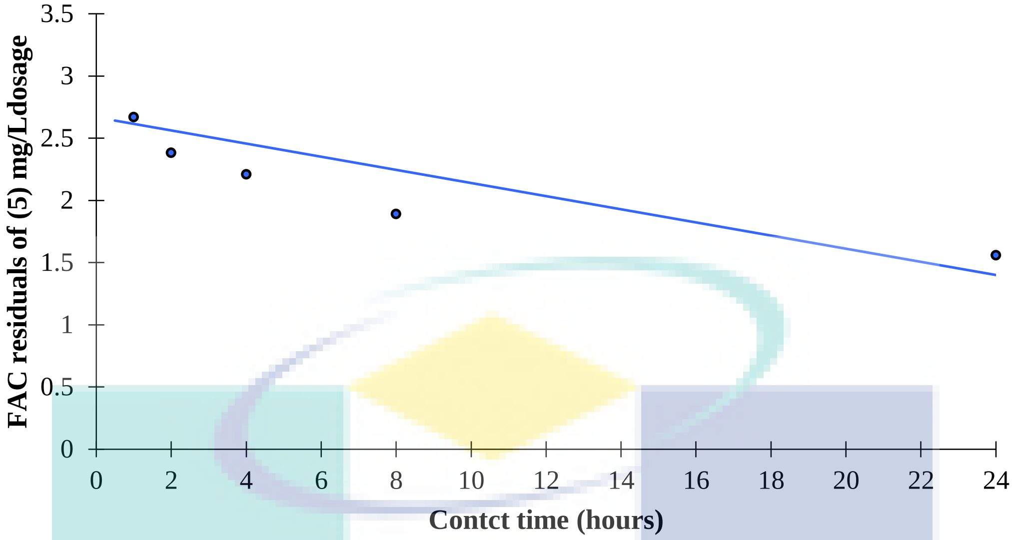
Fitted Line Plot for Linear Model

Y = 2.647 - 0.07095 X

Statistics	Selected Model Linear
R-squared (adjusted)	95.73%
P-value, model	<0.005*
P-value, linear term	<0.005*
Residual standard deviation	0.134

***** *Statistically significant (p < 0.05)*

The regression of FAC residuals versus contact time of 4.5 mg/L dosage



The correlation relation between FAC residuals and contact time of 5.0 mg/L dosage

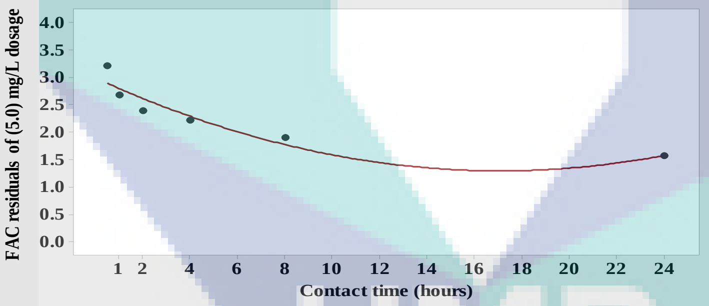
Regression for FAC residuals (5.0) mg/L vs Contact time

Y: FAC residuals of (5.0) mg/L dosage

X: Contact time (hours)

Fitted Line Plot for Quadratic Model

Y = 2.986 - 0.1985 X + 0.005812 X^2



Statistics	Selected Model Quadratic
R-squared (adjusted)	81.02%
P-value, model	0.038*
Residual standard deviation	0.254

***** *Statistically significant (p < 0.05)***

The regression of FAC residuals versus contact time of 5.0 mg/L dosage

APPENDIX G

Malaysian Drinking Water Quality Standards (MDQWS)

Parameters	Maximum Acceptable Values
Physiochemical Parameters	
Turbidity	5.0 NTU
pH	6.0 – 9.0
Conductivity	1000 (μS/Cm)
Salinity	1.0 ($_0$ /oo)
TSS	50 (mg/L)
TDS	1000(mg/L)
DO	5-8 (mg/L)
Ammonia Nitrogen	1.5 (mg/L)
Chloride	200 (mg/L)
Zinc	3.0 (mg/L)
Hardness as:	500 mg/L as total hardness
Calcium and	250 mg/L
Magnesium	250mg/L
Microbiological	
Total Coliform	0 in 100 mL
E. coli	0 in 100 mL
Fecal coliform	0 in 100 mL
Chlorine Residuals	0.2- 0.5 mg/L

APPENDIX H

World Health Organization Water Quality Standards (WHO)

Parameters	Maximum Acceptable Values
Physiochemical Parameters	
pH	
Turbidity	6.5- 8.5
Conductivity	5.0 NTU
Salinity	1000 µS/Cm
TDS	1.0 $_{0}$ /00
TSS	1000 mg/L
DO	50 mg/L
Ammonia Nitrogen	8 mg/L
Chloride	1.5 mg/L
Zinc	250 mg/L
Hardness as:	3.0 mg/L
Calcium	500 mg/L as total hardness
Magnesium	250 mg/L
	250 mg/L
Microbiological Parameters	
Total coliform	0 in 100 mL
E. coli	0 in 100 mL
Fecal coliform	0 in 100 mL
Chlorine Residuals	0.2- 5.0 mg/L

LIST OF PUBLICATIONS

Qasim, B., Abdul Syukor A.R, Nurul Islam Siddique, Sulaiman, S., Nur Hamizah, H2015. Controlling Assessment of Disinfection by Products in Drinking Water- A Review. International Journal of Innovation and Science, Engineering & Technology. *Volume (2) Issue 12. (2015).*

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Ban Qasim, Abdul Syukor Abd. Razak, MD. Nurul Islam Siddique, The Microbiological Quality of Harvested Rainwater System for Domestic Use in Gambang, Malaysia. American Water Works Association Annual Conference & Exposition. ACE, 2017. Philadelphia, Pennsylvania, USA.

Ban Qasim, Abdul Syukor Abd. Razak, MD. Nurul Islam Siddique,Sodium Hypochlorite Dosage for Rainwater Harvesting System for Rainwater Harvesting System for Potable Use in Gambang, Malaysia. American Water Works Association, Water Quality Conference, 2017. Portland, Oregon.